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The Container Tree Nursery Manual • Volume Two

Containers and Growing Media

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Volume Six	Seedling Propagation
Volume Seven	Seedling Processing, Storage, and Outplanting

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The Container Tree Nursery Manual

Volume Two
Containers and Growing Media

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Containers and Growing Media

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Preface

Work on the first comprehensive technical manual on the production of container tree seedlings, "How to grow tree seedlings in containers in greenhouses" by Richard W. Tinus and Stephen E. McDonald, was begun in June 1975 and was published by the USDA Forest Service as a General Technical Report (GTR RM–60) in May 1979. This manual achieved worldwide acceptance as the primary reference on the culture of container tree seedlings. "How to grow tree seedlings in containers in greenhouses" was originally intended as an interim publication and has been reprinted several times; however, it is currently out of print.

In 1982, plans were begun for writing a new container nursery manual based on "How to grow tree seedlings in containers in greenhouses" but adding several new chapters. The writing team consisted of Thomas D. Landis, Richard W. Tinus, Stephen E. McDonald, and James P. Barnett. Realizing that container nursery management had changed considerably over the previous decade, the team surveyed container tree nursery practices in North America in 1984. The Container Nursery Survey was distributed to 135 container nursery facilities in the United States and Canada. Response to the survey was excellent: 78 of 135 surveys were returned. Information from the survey has been used to determine writing priorities and emphasis, and information from it has been included in many of the chapters in this manual.

The Container Tree Nursery Manual consists of a series of separate, sequential volumes. Each volume contains chapters on closely related subjects concerning the production of tree seedlings in containers. The volumes can be accumulated and used as a complete nursery manual, or can be used separately by specialists needing information on a particular subject. Because several subjects must be discussed in more than one volume there will be some redundancy in the Manual. Such repetition is justified, however, because most readers will be using the Manual as a technical reference and will not be reading the entire text.

The Container Tree Nursery Manual is structured around an outline of numerical organizational headings that allow the reader to quickly locate a specific subject without referring to an index. The general outline of volume and chapter titles is as follows:

Volume One Planning, Development, and Management
- Chapter 1 Initial Planning and Feasibility Assessment
- Chapter 2 Site Selection
- Chapter 3 Nursery Layout and Growing Facilities
- Chapter 4 Nonstructural Equipment and Controls
- Chapter 5 Auxiliary Equipment and Buildings
- Chapter 6 Shadehouses, Bedhouses, and Tunnels
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Volume Two Containers and Growing Media
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Volume Three Container Nursery Environment
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Volume Four Seedling Nutrition and Irrigation
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Volume Five The Biological Component: Nursery Pests and Mycorrhizae
- Chapter 1 Disease and Pest Management
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Volume Six Seedling Propagation
- Chapter 1 Stock Types and Growing Schedules
- Chapter 2 Seed Factors and Presowing Treatments
- Chapter 3 Sowing and Other Propagation Methods
- Chapter 4 Establishment Phase
- Chapter 5 Rapid Growth Phase
- Chapter 6 Hardening Phase

Volume Seven Seedling Processing, Storage, and Outplanting
- Chapter 1 Processing and Storage
- Chapter 2 Handling and Transportation
- Chapter 3 Outplanting

This Manual is based on the best current knowledge on container tree nursery management and should be used as a general reference. Recommendations were made using the best information available at the time and are, therefore, subject to revision as more knowledge becomes available. Much of the information in this manual was developed for western and southern conifer seedlings. Although the authors attempted to include information for species from other geographical areas, because of the wide variation in individual species responses, container nursery managers will need to adapt these principles and procedures to their own nursery situation. There is no substitute for individual experience, and recommended cultural practices should be tested before being implemented on an operational scale.

Trade names are used throughout the Manual but are only provided as examples, and no endorsement of specific products, or the exclusion of equally suitable products, is implied. The mention of specific pesticides is intended only for general information and should not be construed as an endorsement. Because of frequent changes in pesticide registration and labeling, the reader should check with local authorities to make sure that an intended use is both safe and legal. Remember that pesticides can be harmful to humans, domestic animals, desirable plants, and fish or other wildlife if they are not handled or applied properly. Use all pesticides selectively and carefully, following the label directions. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

The Container Tree Nursery Manual was organized into separate volumes to allow for revisions and updating. The authors request that readers bring any errors in the text to their attention and also offer suggestions for improvement. Submit any suggestions to Thomas D. Landis, USDA Forest Service, State and Private Forestry, PO Box 3623, Portland, OR 97208.

Many people have been instrumental in the writing of this manual, and the authors would like to thank them for their suggestions and encouragement. Technical review of such a large publication involves considerable work, and the authors are extremely grateful for the invaluable service provided by the following nursery professionals for volume two:

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The Container Tree Nursery Manual

Volume Two
Containers and Growing Media

Chapter 1
Containers: Types and Functions

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2.1.1 Introduction

2.1.1.1 History of container use in forest nurseries

Although ornamental plants have been grown in containers since the early days of human civilization (Matkin and others 1957), the production of forest tree seedlings in containers is a relatively recent innovation. One of the first large-scale uses of container tree seedlings in North America was during the Great Plains Forestry Project of the 1930's. A tarpaper pot system was developed to produce hardy container seedlings for the harsh environmental conditions encountered in shelterbelt plantings (Strachan 1974).

The first large-scale production of reforestation seedlings in modern plastic containers was in Canada: the "Walters Bullet" in British Columbia (Walters 1974) and the "Ontario Tube" in Ontario (Reese 1974) (fig. 2.1.1). Based on these early prototypes, other containers were developed and tested in Canada and the United States during the 1960's and early 1970's, including some that are still popular today: Styrofoam® blocks (Sjoberg 1974), Spencer-Lemaire (S/L) Rootrainers® (Spencer 1974), and the Ray Leach Single Cell® system (Allison 1974). In addition to these North American products, the "Japanese paperpot" was adapted in Scandinavia (Rasanen 1982) and subsequently imported to the United States and Canada.

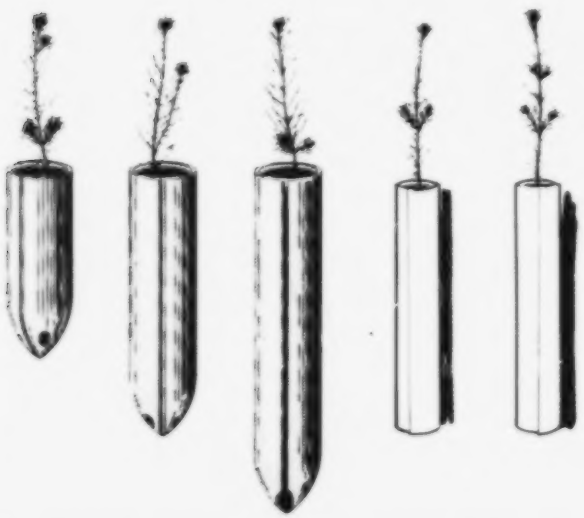


Figure 2.1.1—*The Walters bullet (left) and the Ontario tube (right) were two early container designs used for growing forest tree seedlings in Canadian nurseries (from Carlson 1983).*

Many types of containers have been tested in North American forest tree nurseries during the past 20 years (fig. 2.1.2), but the perfect container has yet to be developed. In reality, no single container will ever fill the needs of every nursery manager because of differences in nursery cultural practices or outplanting site conditions. Which is the best container for a given purpose will depend on the specific objectives of the nursery and of the reforestation system.

2.1.1.2 Terminology

Certain terms that are used to describe containers in forest tree nurseries need to be defined here. In container nurseries that produce ornamental tree seedlings, the individual containers are relatively large, single containers that are called **pots** or **cans.** Reforestation stock, by comparison, is grown in relatively small-volume containers. The individual containers are often referred to as **cells** or **cavities**, and are usually produced in aggregates called **blocks**, **trays**, or **racks** (fig. 2.1.3). In the common nursery vernacular, however, the term **container** can refer to a single cell or the entire block.

Seedlings grown in containers have been called containerized, or container-grown, but they will be known as **container seedlings** in this publication. This term is simple and definitive and is consistent with the most current terminology in the ornamental nursery trade.

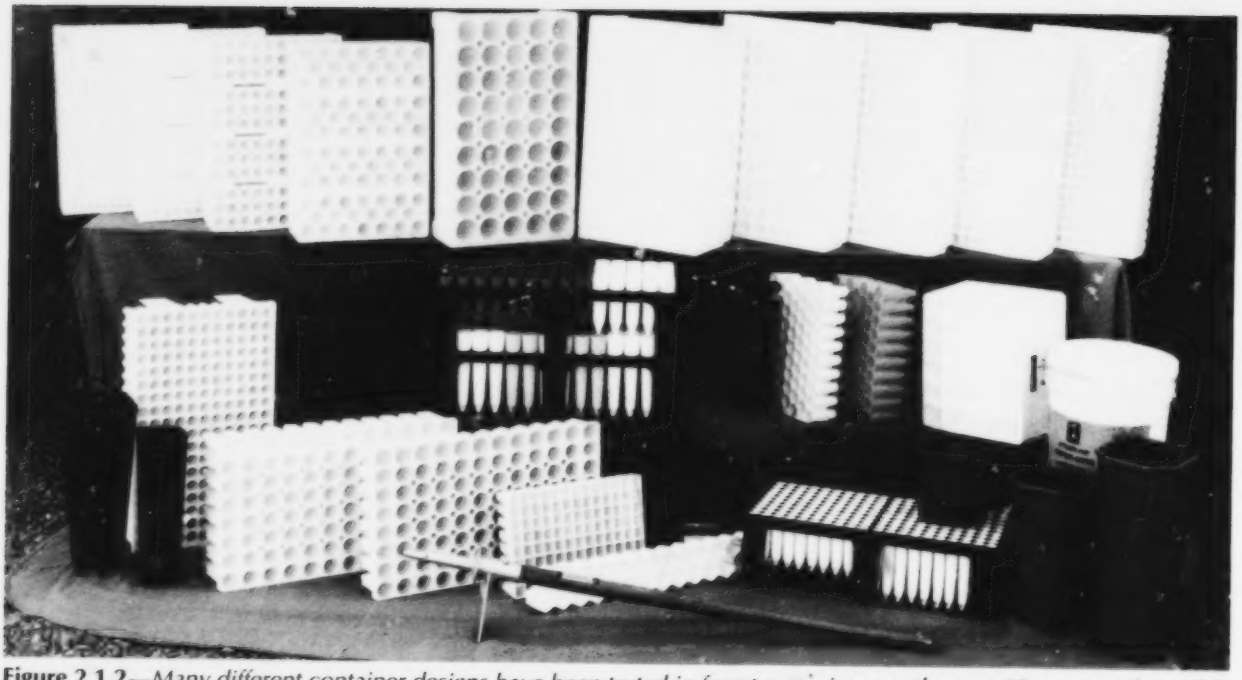


Figure 2.1.2—*Many different container designs have been tested in forest nurseries over the past 25 years, and a wide variety of brands and sizes is currently available (courtesy of Eric Stuewe).*

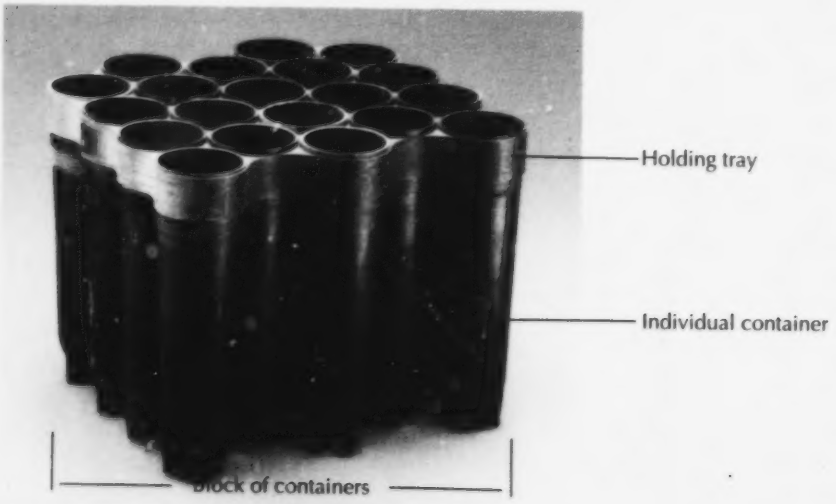


Figure 2.1.3—*Individual containers, or cells, are joined together by a tray or rack into a basic handling unit called a block; this container is the Deepot®.*

2.1.2 Characteristics of Containers for Forest Nurseries

The properties of the ideal container for raising forest tree seedlings have been debated for many years. Although containers can be compared in several different ways, the most appropriate is the functional approach. The primary function of any container is to hold a discrete supply of growing medium, which in turn supplies the seedling roots with water, air, mineral nutrients, and physical support while the seedling is still in the nursery.

Forest tree seedling containers must perform certain other functions, however, that reflect the special requirements of conservation or reforestation plantings. Some of these container characteristics shape seedling growth in the nursery, such as design features to prohibit root spiralling. Other operational characteristics of containers are related to economic and management considerations both at the nursery and on the outplanting site. These characteristics are listed and discussed in detail in the following sections.

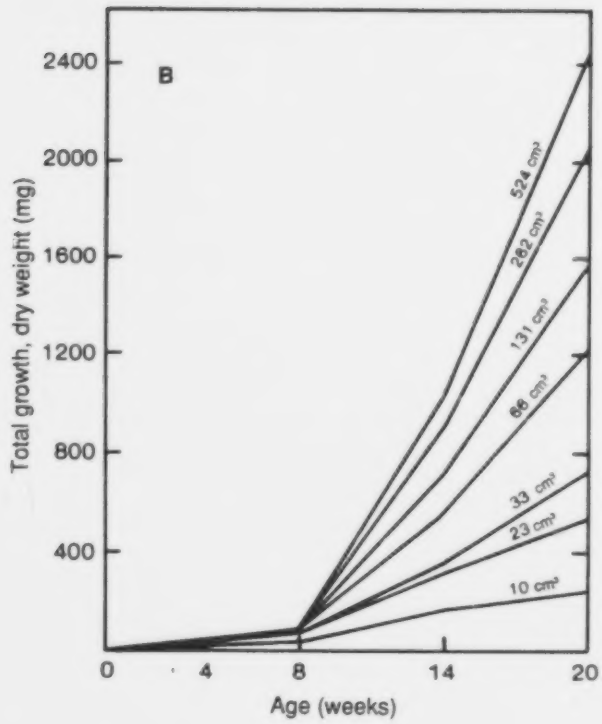
2.1.2.1 Characteristics that influence seedling growth

Tree seedlings differ from most ornamental container crops because conservation and reforestation seedlings are essentially a root crop. Most ornamental container crops are grown for their flowers or foliage, but the quality of a tree seedling is determined by its outplanting performance—both initial survival and subsequent growth. Tree seedling survival and growth are directly related to the ability of the root system to promptly regenerate new roots (known as **root growth potential**, or RGP) and grow out into the surrounding soil (Ritchie 1984). For this reason, many tree seedling container features are designed to encourage the seedling to form a good root system in the nursery and to protect these roots until the seedling is outplanted. The relative health and vigor of the root system is also reflected in the morphology and growth of the seedling shoot, and for this reason many of the following container characteristics were designed to enhance this root–shoot relationship.

Container size. The "best" container for a particular seedling crop will depend on both biological and economical factors. Biological considerations include the size of the seed or cutting, the ultimate size of the crop plant, and the environmental conditions on the outplanting site. Economically, the initial cost and availability of the container and the amount of available growing space are primary considerations.

Although in the current forest nursery vernacular container size means volume, the concept of size includes all dimensional aspects, including volume, height, diameter, and shape. The volume of the cavity is one of the most obvious and important characteristics of a container because, in general, the larger the container, the larger the seedling that can be produced (Kinghorn 1974). North American container tree nurseries currently use containers ranging in volume from a minimum of 40 cm^3 (2.5 cubic inches) to a maximum of 492 cm^3 (30.0 cubic inches) (table 2.1.1).

When tree seedlings are grown in a series of different container types, seedling size generally increases with the rooting volume of the container (fig. 2.1.4A) (Alm and others 1982). Container volume has a significant effect on the size and growth rate of lodgepole pine (fig. 2.1.4B & C) (Endean and Carlson 1975) and white spruce (Carlson and Endean 1976) seedlings when they are grown in a variety of different container sizes. Root, shoot, and total dry weight as well as shoot length increased significantly with increasing container volume, whereas the shoot–root ratio was unaffected (table 2.1.2). Seedling growth comparisons between different container types must consider both container volume and growing density (the spacing between containers), however, because containers with the same volume can have different growing densities. This important relationship between container capacity and growing density is discussed in the following section.



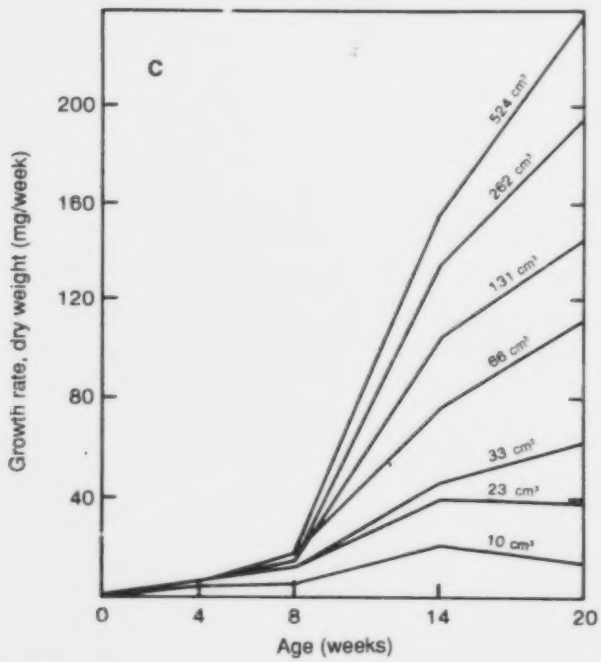


Figure 2.1.4—*Container size is one of the most significant factors affecting the ultimate size of tree seedlings, such as these lodgepole pines (**A**). In growth trials with this species, both total seasonal growth (**B**) and growth rate (**C**) were found to increase with the size (volume) of the container. (**B** and **C** from Endean and Carlson 1975).*

Table 2.1.1—*Characteristics of common container types used in U.S. and Canadian forest tree seedling nurseries*

	Dimensions of cell (diameter × height)		Maximum capacity		Cell density		1984 nursery use
	cm	in	cm^3	in^3	cells/m^2	cells/ft^2	%
Containers planted with seedling							
Paper containers							
Paperpot							
408	4 × 8	1.6 × 3.2	70	4.3	1,000	93	7
Other sizes							2
Total							9
Containers removed before outplanting							
Individual cells							
Ray Leach Single Cells®							
Fir cells	2.5 × 12.2	1.0 × 4.8	49	3.0	1,076	100	1
Pine cells	2.5 × 16	1.0 × 6.3	65	4.0	1,076	100	6
Super cells	3.8 × 20	1.5 × 8	164	10.0	527	49	8
Other sizes							1
Total							16
Book or sleeve containers							
Spencer-Lemaire Rootrainers®							
Ferdinand	2 × 2 × 10	0.8 × 0.8 × 4	40	2.5	1,280	119	4
Fives	2.5 × 2.5 × 10.5	1 × 1 × 4	62	3.8	882	82	1
Hillsons	3.8 × 3.8 × 12.5	1.5 × 1.5 × 5	165	10.5	398	37	2
Tinus	3.8 × 5.1 × 18.5	1.5 × 2 × 7.2	350	21.5	516	48	3
Total							10
Block containers							
Styrofoam® blocks							
2 (211)	2.5 × 11.4	1 × 4.5	41	2.5	1,032	96	9
2A (211A)	2.5 × 11.4	1 × 4.5	41	2.5	1,108	103	9
4 (313)	3 × 12.5	1.2 × 5	66	4.0	807	75	13
4A (313A)	2.8 × 13.2	1.1 × 5.2	62	3.8	936	87	5
5 (315)	3.0 × 15.2	1.2 × 6	77	4.7	667	62	2
7 (323)	3.0 × 22.9	1.2 × 9	121	7.4	764	71	2
8 (415A)	4.1 × 15.2	1.6 × 6	131	8.0	441	41	6
20 (615)	6.1 × 15.2	2.4 × 6	336	20.5	215	20	2
Colorado	5 × 5 × 20	2 × 2 × 8	492	30.0	270	25	2
Other sizes							1
Total							51
Kopak Multi-pot®							
#1	3 × 9	1.2 × 3.5	57	3.5	850	79	2
#2	3 × 12	1.2 × 4.8	65	4.0	850	79	8
Other sizes							1
Total							11
Other container types							3
Grand Total							100

Because containers types are continually evolving, some of these statistics may have changed. This information is presented to give the reader an idea of the products that are available. Contact suppliers (table 2.1.4) for current information.

Source: Container Nursery Survey (1984)

The major constraint on container volume is economical, not biological, because (a) larger containers take up more growing space, (b) seedlings grown in large containers require longer growing periods for the seedling root system to occupy the container completely, and (c) large containers are bulkier to handle during shipping and outplanting. Nursery managers should select a container that will produce an acceptable seedling at the highest practical growing density, in the shortest rotation time, and one that is suited to the conditions of the outplanting site (the effect of container volume on outplanting success is very important and is discussed in more detail in section 2.1.2.2).

Optimum container size varies according to many different factors, including growing density, seedling species, size of seedling desired, type of growing medium, environmental conditions, and length of the growing season. There does appear to be a minimum container size for conservation and reforestation stock, however. Scarratt (1972) found that the growth of white spruce seedlings varied significantly in containers of three different diameters (12, 19, and 31 mm), but that only seedlings in the larger container (31 mm) achieved acceptable growth during a normal production period. Barnett and Brissette (1986) found that species that are intolerant of crowding, such as longleaf pine, grew bigger in large-volume containers with a low growing density. Other tolerant pine species, such as loblolly pine, could be produced in small-volume containers with a high growing density. Hardwood species generally require larger volume containers, with their concomitant lower growing density, than do conifer seedlings because the large leaves of hardwood species intercept more water and nutrients and generate more shade.

Other aspects of container size are also important. One of the most biologically and culturally important container dimensions is height, because of its effect on the water-holding properties of the growing medium (see section on container properties that affect growing medium moisture content). Carlson and Endean (1976) found that the height–diameter ratio had a significant effect on the growth of white spruce seedlings: a container with a 1:1 height–diameter ratio produced heavier seedlings than containers with 3:1 or 6:1 configurations. This effect was apparently species-specific, however, because lodgepole pine did not show any growth differences when grown in the same three container sizes (Endean and Carlson 1975). Boudoux (1970) studied root system growth in relation to container dimensions and concluded that, to increase root density, diameter is more important than height.

Table 2.1.2—*Effect of container volume on the morphology of lodgepole pine seedlings at 20 weeks of age*

Container volume (cm^3)	Seedling biomass OD weight (mg)			Shoot/root ratio	Shoot length (mm)
	Root	Shoot	Total		
10	96 g	150 f	246 g	1.6 a	34 g
23	222 f	319 e	541 f	1.4 ab	41 f
33	335 e	389 e	724 e	1.2 b	48 e
66	498 d	722 d	1,220 d	1.5 a	60 d
131	638 c	936 c	1,573 c	1.5 a	68 c
262	790 b	1,265 b	2,055 b	1.6 a	83 b
524	897 a	1,544 a	2,440 a	1.8 a	89 a

Values in columns with no letters in common differ significantly at the P = 0.05 level using Duncan's multiple range test.
OD = ovendry.
Source: Endean and Carlson (1975).

Forest tree seedling containers are produced in a variety of shapes: round, rectangular, hexagonal, or square in cross-section, and most are tapered from top to bottom. Although useful for seedling extraction, an extreme taper may be biologically detrimental, however, because normally the majority of roots are produced in the bottom of a container (Tinus 1974). The actual shape of the root plug is probably not operationally significant unless the seedling is going to be planted with a planting tool, such as a dibble, that has a specific size and shape. Container seedlings that are to be transplanted into bareroot nursery beds as plug-plus-one seedlings or outplanted in a transplanting machine must have a root plug that can be handled efficiently by the planting equipment.

Container spacing. The distance between the individual cells in the block generates seedling growing density, one of the most important container characteristics affecting seedling growth. The spatial arrangement of cells within the block also has economical implications, however. Tree seedlings require a certain minimum amount of growing space, which varies with species and age. Nursery managers, on the other hand, need to produce the maximum number of seedlings per unit area of growing space.

In general, container seedling quality increases with a corresponding decrease in growing density. Tanaka and Timmis (1974) studied the effect of growing density on seedling characteristics and concluded that Douglas-fir seedlings produced at lower densities had physical and physiological properties that lead to improved outplanting performance, including greater dry weight and smaller height–diameter and shoot–root ratios.

When comparing tree seedlings produced in different container types, seedling growing density should be as important a consideration as cell volume. Direct comparisons are often difficult to interpret because there is a definite interaction between these two factors (Barnett and Brissette 1986). Most published comparisons of containers of the same volume do not consider the effects of seedling density and therefore their conclusions should be interpreted accordingly. Timmis and Tanaka (1976) reported the results of one of the few properly designed container comparison studies that considers the interaction between cell volume and cell density. They grew Douglas-fir seedlings at different growing densities in containers with the same volume, and found that seedling morphology and weight varied between the different seedling spacings (table 2.1.3). Shoot height increased with increasing density, probably as a result of greater competition for light between the seedlings. Stem diameter, shoot weight, and root weight, however, decreased with closer spacing (which is also reflected by the larger shoot–root ratio at the greater densities).

Seedlings produced at closer spacings grow taller and have smaller stem diameters (caliper) and lower biomass (dry weight) than those grown further apart. Scarratt (1972) grew white spruce seedlings in three different volume containers at three different growing densities and found that shoot height, stem caliper, and dry weight increased with both container volume or spacing (fig. 2.1.5). For this species, however, container volume was more important than seedling growing density, and the author concluded that the use of a larger container was both more biologically effective and cost efficient than using smaller containers at wider spacings. In trials

Table 2.1.3—*Spacing between containers generates seedling growing density and affects the morphology and weight of 5-month-old Douglas-fir seedlings*

Seedling spacing (cm)	Growing density (seedlings/m²)	Shoot height (cm)	Stem caliper (mm)	Shoot dry wt. (g)	Root dry wt. (g)	Shoot/ root ratio
6.0	270	11.0 a	1.93 a	0.67 a	0.45 a	1.5 a
4.3	540	11.9 b	1.80 b	0.62 b	0.33 b	2.0 a
3.5	810	11.6 ab	1.71 c	0.50 b	0.30 b	1.8 a
3.0	1,080	16.3 c	1.68 c	0.57 b	0.26 b	2.3 b

Values in columns with no letters in common differ significantly at P= 0.05, according to Duncan's multiple range test.
Source: Adapted from Timmis and Tanaka (1976).

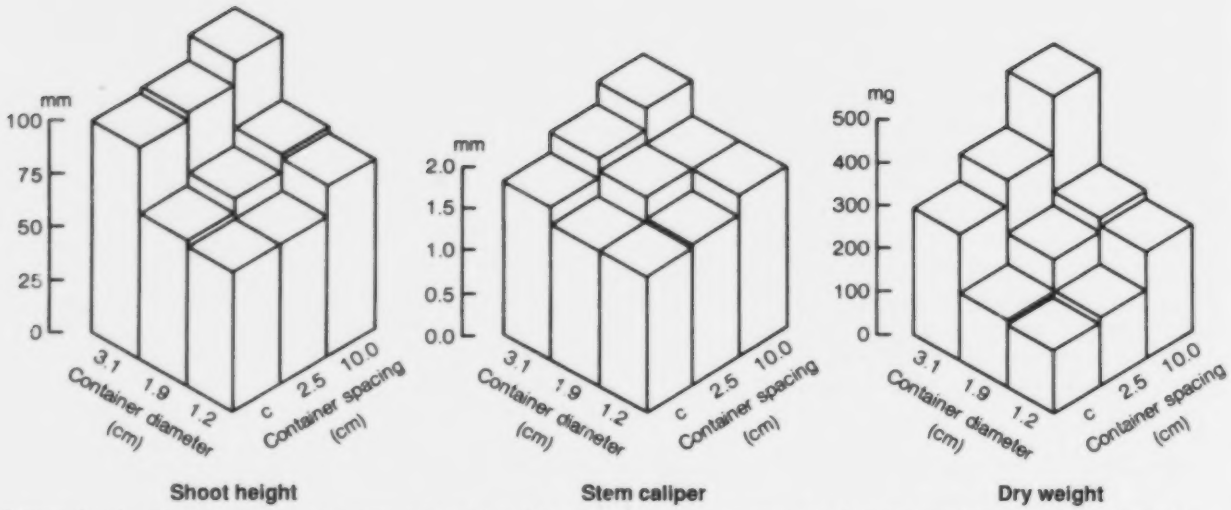


Figure 2.1.5—*Container size (diameter) as well as the space between containers dictates seedling growing density in the nursery, which in turn affects shoot height, stem caliper, and seedling dry weight (Scarratt 1972).*

with extruded peat containers, Hocking and Mitchell (1975) found that all growth characteristics of lodgepole pine, white spruce, and Douglas-fir seedlings increased when containers were larger or the space between cells was wider.

Container spacing also has some other biological and cultural implications on seedling growth. Timmis and Tanaka (1976) reported that seedlings grown at lower densities received ten times more photosynthetically active radiation in their lower crowns and had lower water potential than seedlings grown at closer spacings. The temperature of the growing medium was also higher in closely spaced containers. It is also more difficult for irrigation water and liquid fertilizers to penetrate dense patches of seedling foliage. Foliar diseases, such as grey mold, are more of a problem in densely grown seedlings because the fungus is able to invade the weaker, senescent foliage in the lower part of the seedling crown. Grey mold is also encouraged by the higher relative humidity and lower light in dense groups of seedlings. A Styrofoam block modified with vents between the cells reduced grey mold incidence on Douglas-fir seedlings due to better air circulation (Peterson and Sutherland 1989). Growing density apparently also affects seedling hardiness because seedlings grown at higher densities suffered more cambial frost damage than those grown at greater spacings (Timmis and Tanaka 1976).

The effect of seedling growing density is further complicated by the length of the growing season. Barnett and Brissette (1986) reported that, in southern pines grown for only 10 weeks, the effects of seedling density were not critical. However, when the growing season was extended to 12 or 14 weeks, seedling dry weight decreased with increasing growing densities (fig. 2.1.6A); the effects of growing density and age on seedling height were less pronounced, however (fig. 2.1.6B). This size difference also had a carry-over effect: seedlings grown at the lower densities had higher survival rates and more height growth when measured 2.5 years after outplanting than did seedlings grown at higher densities. Based on these results, the authors recommend that southern pines should not be produced in containers with densities greater than 1,075 seedlings/m^2 (100 per square foot).

Seedling species also respond differently to the effects of crowding and, theoretically at least, broadleaved species and shade-intolerant conifers should be produced at lower growing densities than conifers or more-shade-tolerant species. Although many studies that tested the relationship between species and container type have been published, few have attempted to separate the effects of container volume from growing density (see previous section). As an example, Stauder and Lowe (1984) reported that container density did not affect the growth or field survival of baldcypress seedlings, although the containers used in their study were relatively

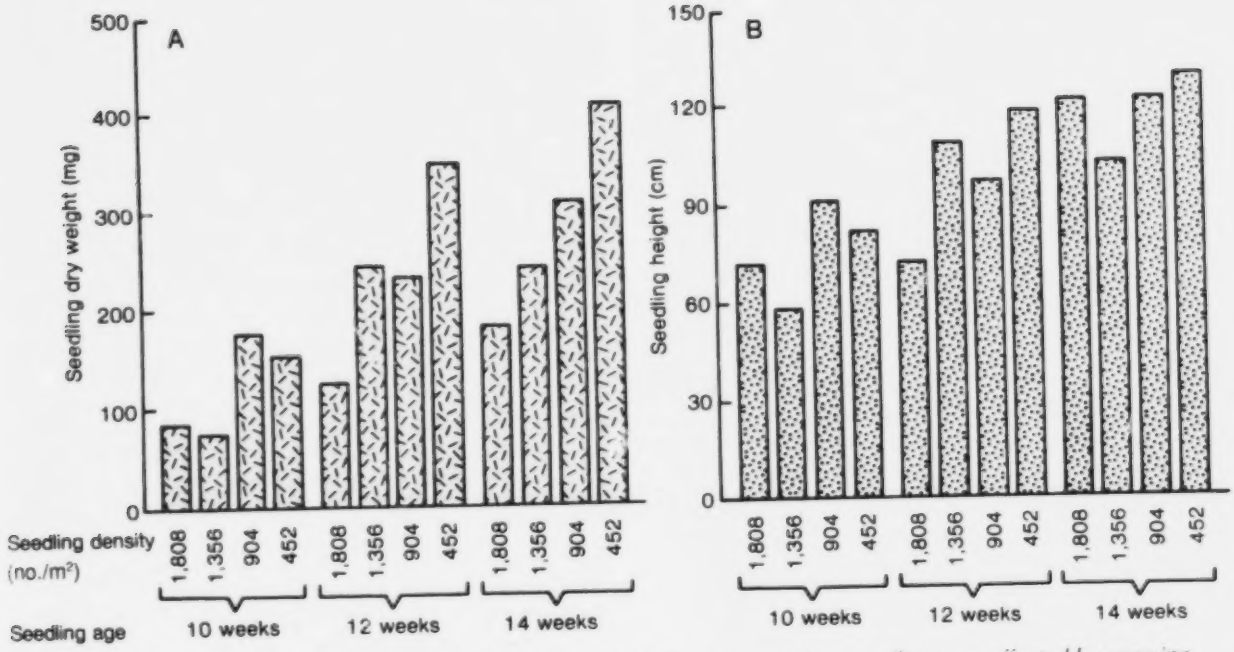


Figure 2.1.6—*Although both the dry weight and height of loblolly pine container seedlings are affected by growing density, height is less influenced as the seedlings grow older (adapted from Barnett and Brissette 1986).*

large Dee-pots*, which produce a very low growing density of 215 cells/m² (20 per square foot).

Design features to control root growth. One of the most serious problems in container tree seedling culture is the tendency of tree seedling roots to spiral around the inside of the container. Seedling roots grow geotropically, but if they do not meet any physical obstruction, they may tend to grow laterally around the side of the container.

Root spiralling will not adversely affect growth while the seedling remains in the nursery, but it can seriously reduce seedling quality after outplanting. Spiral roots prevent the seedling from becoming properly established in the surrounding soil, which can result in frost-heaving, toppling, or even strangulation (Burdett 1979).

Although it can occur in almost any container type, root spiralling is most serious in round, smooth-walled plastic containers. Girouard (1982) grew 4 species of conifer seedlings in 3 different types of containers and found that the only one in which root spiralling occurred was the round Quebec tube. Paper containers present two root control problems: root spiralling in polyethylene-coated paper containers and root growth between cavities in untreated paper containers (Dong and Burdett 1986).

The problem of root spiralling has been at least partially solved by designing containers with vertically oriented ridges, ribs, or grooves (fig. 2.1.7A) that protrude into the growing medium and present an obstacle to spiral root growth; Kinghorn (1974) recommended ribs about 2 mm (0.08 inch) high on the inner cavity wall. These ribs intercept spiralling roots and force the developing roots to grow downward to the drainage hole (fig. 2.1.7B), where they stop growing because of the low humidity and become **airpruned**. Most types of containers used in forest tree nurseries have some sort of antispiralling rib design, and one container manufacturer has even incorporated this feature into its brand name, the Spencer-Lemaire Rootrainer* (fig. 2.1.7A).

Root spiralling occurs in most tree species but has been most serious in pines. Girouard (1982) found that all four species of conifers grown in Quebec tubes exhibited some degree of root spiralling but that it was worse in the pine species (fig. 2.1.8). Even with pines, however, there is variation; Barnett and Brissette (1986) report that

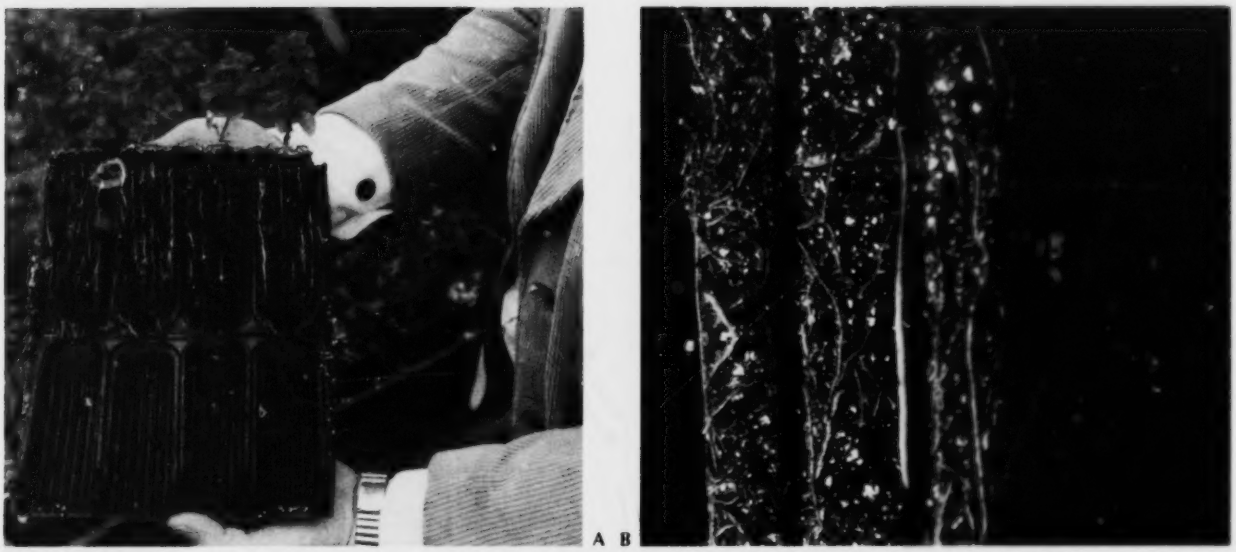


Figure 2.1.7—*Vertical grooves* **(arrow)** *in the sidewall of this Spencer-Lemaire Rootrainer® container* **(A)** *prevent root spiralling by orienting root growth downward* **(B).**

longleaf pine is more prone to root spiralling than are loblolly and slash pines. Root spiralling and other types of abnormal root growth become more serious the longer the seedlings remain in the container (Barnett and Brissette 1986); this tendency was particularly significant for jack pine (fig. 2.1.8). (Chemical treatments to control root spiralling are discussed in section 2.1.4.)

When the seedling roots reach the bottom of the container, they must be forced to air-prune or they will continue growing downward along the support bench (fig. 2.1.9A). This exterior root growth makes the seedling difficult to extract at the end of the growing season, resulting in damaged root systems. Air-pruning of roots at the drainage hole is encouraged by providing a layer of air below the container (fig. 2.1.9B). Armson and Sadreika (1979) reported that a 1.25-cm (0.5-inch) air gap beneath the container was most effective. Some containers are formed with an external rib to create this air space (fig. 2.1.9C). With containers that have no built-in support to encourage air-pruning, some growers use benches with a mesh top (fig. 2.1.9D) or design their benches to support the containers so that an air layer is created. Other growers allow the roots to grow out the bottom of the container and then mechanically prune the roots before the seedlings are extracted. The biological implications of this practice have not been scientifically examined, but the authors recommend natural air-pruning if at all possible.

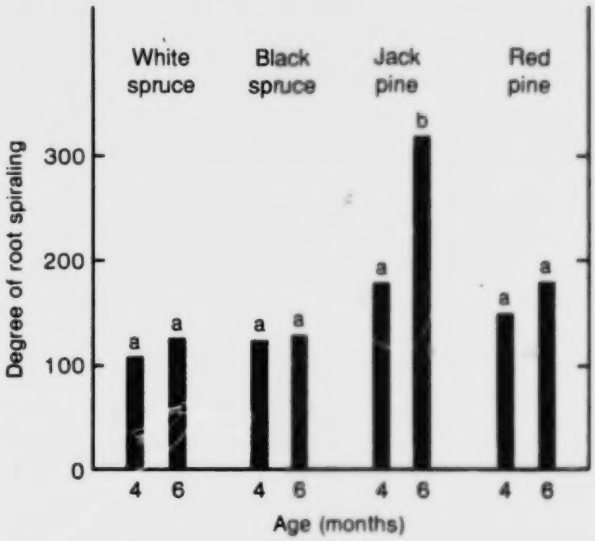
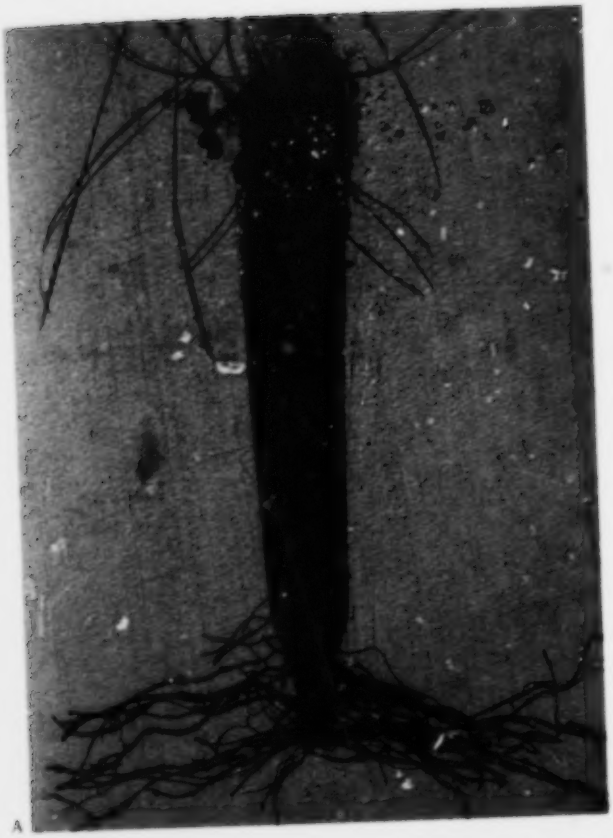
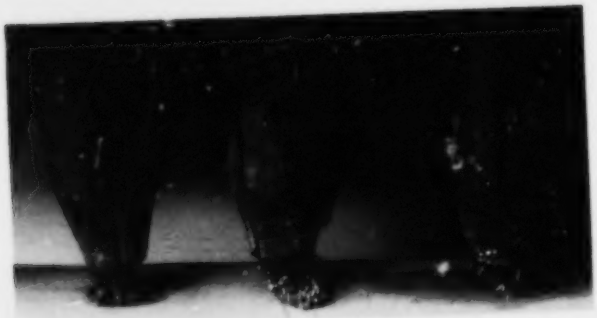


Figure 2.1.8—*Some degree of root spiralling occurred in all four species of conifer seedlings in the round, smooth-walled Quebec tube container, but was more extensive in the pines. Spiralling did not significantly increase with time, however, except for the jack pine seedlings. Bars with the same letter are not significantly different at the P = 0. 01 level. (Girouard 1982).*



A



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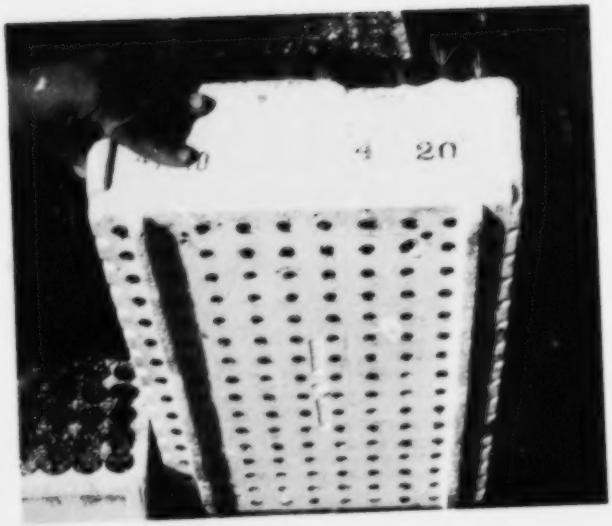

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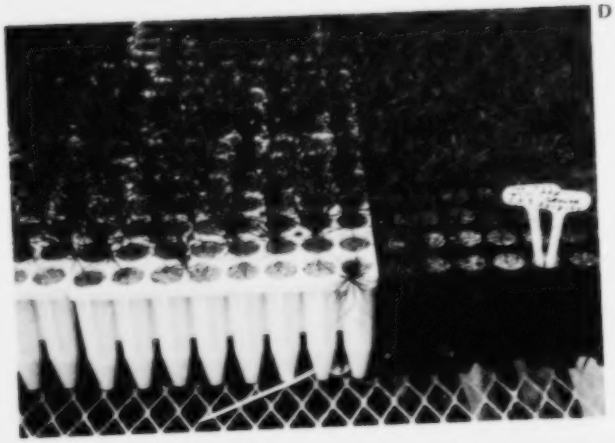
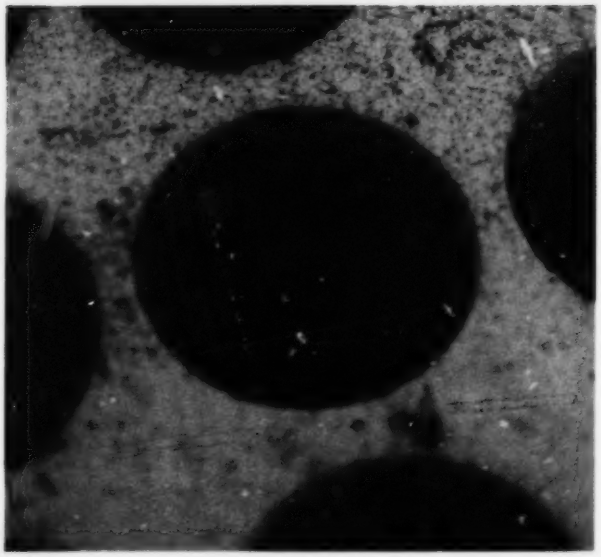


D

Figure 2.1 9—*If they are not forced to "air-prune," seedling roots will continue to grow downward and out the bottom of the container* **(A).** *Air pruning is encouraged by providing a layer of air under the container* **(B).** *Some types of containers are structurally designed to develop an air layer* **(C),** *whereas others should be placed on benches made of screen or other material that promotes air-pruning* **(D).**

One other container characteristic that affects root growth is the smoothness of the inside walls of the container cells. Roots of some seedlings are very fine and tend to grow into any cracks or seams in the walls of the containers. Western redcedar and Alaska-cedar are notable in this respect and, in British Columbia, these species are grown in smooth-walled S/L Rootrainers instead of the standard Styrofoam blocks, which have rough walls (Matthews 1983). This root ingrowth makes these seedlings difficult to remove from the container during seedling extraction, and the roots extending from the extracted plugs make them difficult to plant (fig. 2.1.10A). Torn roots that remain in the containers (fig. 2.1.10B) provide an excellent substrate for root-rotting fungi and may be a significant factor in root disease carryover between successive crops.

A



B

Figure 2.1.10—*Certain species of tree seedlings, such as western redcedar, have very abundant and aggressive roots that penetrate the pores of the inner container wall, making these seedlings very difficult to extract from the container and plant* (**A**). *Torn roots left in the container* (**B**) *can also serve as root disease inoculum for the next crop.*

Container properties that affect growing medium moisture content. Certain features of containers such as container height, container wall permeability, and presence of a drainage hole affect the moisture relationships of growing media. Bassman and others (1989) grew western larch seedlings in 3 different types of containers and found a significant interaction between container type and water regimes.

The effect of container height is discussed in detail in chapter 2 of volume four of this series, but basically the taller the container, the greater proportion of well-drained medium that it will contain. All containers create a perched water table because they maintain a volume of growing medium above a layer of air. Because water molecules are attracted to the growing medium in a container, water does not freely drain from the medium in the bottom of the container, thus creating a perpetually saturated layer of growing medium. The depth of this saturated layer is a function of container height and the physical properties of the growing medium.

Moisture within the growing medium is also affected by the properties of the container wall. Containers composed of permeable materials such as paper or plastic mesh allow water and dissolved salts to move laterally through the container wall and into the growing medium in adjacent containers. The moisture relationships in a block of adjacent paper containers, such as a tray of paperpots (fig. 2.1.11), are similar to a tray of unconfined growing medium, because water and dissolved salts can move freely from one container to the next. Containers with permeable walls, therefore, may require a growing medium with a coarser texture to increase porosity and thus prevent waterlogging.

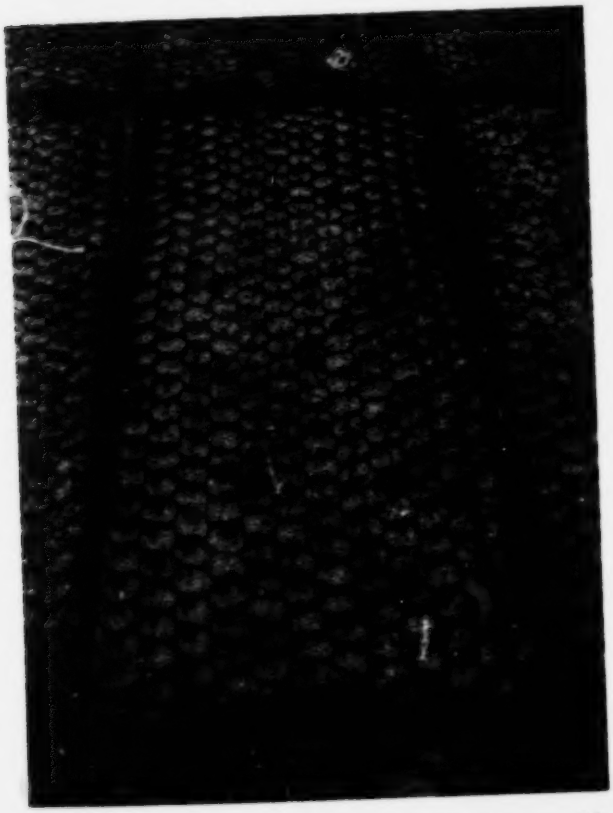


Figure 2.1.11—*Containers constructed out of permeable materials, such as paper, allow water and soluble salts to move laterally between individual cells, which affects the moisture and mineral nutrient relationships of the growing medium.*

All containers must have one or more drainage holes at the bottom to allow excess irrigation water to drain and to encourage excess fertilizer salts to leach out (fig. 2.1.9C). These drainage holes must be as large as possible yet should not permit the growing medium to fall through during the filling operation. Because a mass of root tips eventually develops around drainage holes, they may eventually become plugged and cause drainage problems if they are too small (fig. 2.1.9B). The other function of the drainage hole is to force the root system to air-prune when the roots reach the bottom of the container (see previous section). The benefits of these drainage holes are lost, however, if an air layer is not provided beneath the container (fig. 2.1.9D).

Container properties that affect growing medium temperature. The color and insulating properties of container materials affect the temperature of the growing medium and, therefore, root growth. These properties are important during the growing season because root temperature is affected by the sunlight absorption and the insulating properties of the container material. Insulation of the root system is also important when seedlings are subjected to freezing temperatures during hardening or overwinter storage.

The heat absorption and conduction properties of the container can be significant in the high-energy environment of a container nursery. High root temperatures can inhibit root growth and may even result in seedling mortality (Furuta 1978). Whitcomb (1988), in his discussion of the effects of high root temperatures in container nurseries, emphasizes that considerable variation exists in the heat tolerance of different plant species and even varieties of the same species.

Heat absorption is a function of container color, with darker colors absorbing more solar insolation than lighter ones (fig. 2.1.9D). Containers made of a thicker insulating material, such as Styrofoam®, will conduct less heat than thinner plastic materials. Bassman and others (1989) studied western larch seedling growth in 3 different container types, and concluded that medium in containers with walls made of thin plastic may heat up more rapidly than medium in thicker walled containers. Seedlings growing in the warmer medium had more root growth. However, excessively high root temperatures injure seedling roots. Whitcomb (1988) reported that the temperature of the growing medium just inside the wall of large ornamental seedling containers sometimes reached 48 °C (120 °F) in direct sunlight; Barney (1947)

found that the root systems of several conifer seedlings were killed by only a few hours at these temperatures. Brown (1982) investigated the effect of container color on 3 ornamental species and found that changing the color of the container from black to white reduced growing medium temperatures 7 °C (11 °F) and produced plants of significantly higher quality. Seedlings on the outside of the bench on the sunny side of the growing area are most susceptible to root injury from high root temperatures.

Just as important as insulating seedling root systems against high temperatures is protecting them against cold injury. Roots are much more sensitive to cold injury than shoots, and container seedlings stored outside during the winter can suffer severe injury if their roots are not protected. Containers constructed of materials with a high insulating value, such as Styrofoam, provide more protection than thin-walled containers, although Edwards and Huber (1982) report cold damage even in Styrofoam blocks (cold injury is discussed in more detail in chapter 1 of volume five of this series).

2.1.2.2 Characteristics that affect nursery and outplanting operations

In addition to the characteristics that influence seedling growth, there are other container attributes that affect operational aspects of the nursery/outplanting process. Some container characteristics, such as size, affect operations both at the nursery and on the outplanting site. Because no one container is ideal for all purposes, a nursery manager should consider all the different characteristics and discuss them with customers during the container selection process.

Need to match containers to both the nursery and outplanting system. The entire nursery and outplanting system should be considered during the container selection process. In new nurseries, the physical attributes of the container, such as size and spacing, will determine bench design and therefore seedling production per growing area. Container volume and shape also influence the type of growing medium used as well as the type of filling and sowing equipment. Because of container effects on the moisture content of the growing medium, fertilization and irrigation systems should also be considered during the container selection process. Large volume containers with their inherent lower seedling growing densities will result in faster growth and therefore shorter greenhouse rotations, but large containers also take up more growing space. For container seedlings that will be transplanted into a bareroot nursery seedbed, the type of container affects the type of transplanting machine and the ease of handling at the bareroot nursery.

Container attributes also affect other aspects of the reforestation process, from seed collection to outplanting. Seed size must be considered: species with large seeds, such as oak acorns, will require wider containers than small-seeded species. Seedling handling, transport, and storage are also affected by the size and weight of containers or extracted plug seedlings. Seedlings in large-volume containers are inherently more heavy and bulky to handle at each stage of the harvesting, storage, and outplanting process. Container size and shape may also influence the type of planting tool and other logistical operations on the outplanting site because fewer large seedlings can be packed per shipping carton or carried per planting bag.

Some types of containers were specifically designed to be part of a completely automated sowing and outplanting system. The paperpot was one of the first containers for which a complete filling, sowing, handling, and outplanting system became commercially available (Hoedemaker 1974). The Hiko System®, which was developed in Sweden, can fill and sow about 250,000 cavities in one 8-hour shift, and the containers are mechanically handled at every step in the nursery. On the outplanting site, the containers are carried in specially designed backpacks (Twetman 1988). The convenience of a coordinated container system must be weighed against the cost and the inflexibility of these highly automated systems. Once the container is selected and the nursery and reforestation systems are designed around it, it becomes increasingly difficult to change container types or any other part of the equipment or facilities.

Cost and availability. Although the biological aspects of a specific container are important, cost and availability are often the controlling factors in container selection. Associated expenses, such as shipping and storage costs, must be considered in addition to purchase price. Many containers are produced at only one location and their shipping costs increase as a direct function of distance from the manufacturer; others, such as Styrofoam blocks, are produced or distributed from various locations around the continent and are therefore widely available. Long-term availability must also be considered

in the selection process to insure that ample supplies of the container can be secured in the foreseeable future.

When conducting an economic analysis of different types of containers, the overall cost of seedling production including seedling growing density, amount of growing medium required, and value of the seedling produced must be considered.

Durability and reusability. Containers must be durable enough to maintain structural integrity and contain root growth during the nursery period. The intense heat and ultraviolet rays in container nurseries can cause some types of plastics to become brittle (fig. 2.1.12), although many container plastics now contain ultraviolet inhibitors. Container durability is especially important when considering biodegradable containers because these containers must be durable in the moist, humid conditions of a greenhouse, yet biodegrade within a reasonable period after outplanting.

Some containers are designed to be used only once, whereas others can be reused for 5 or more crop rotations. Reusability must be considered in the container cost analysis because the cost of reusable containers can be amortized over their life span, after adjusting for the cost of handling, cleaning, and sterilizing of the containers between crops.

Ability to monitor growing medium condition and root growth. Although it is easy to monitor the ambient environment and observe seedling shoot growth and phenology, it is more difficult to monitor the condition of the growing medium and the degree of root activity. In a typical container, it is impossible to directly observe the moisture content of the growing medium or root growth without disturbing the seedling. Late in the growth cycle, however, seedlings become large enough to form a firm root plug and can be removed from the container and the condition of the plug examined. Containers have been developed that can be opened to examine the growing medium and root system. Book-type containers (fig. 2.1.7A) are hinged along the bottom of the containers so that they can be opened and reclosed whenever necessary. Sleeve-type containers have a similar feature consisting of two separate but matched sections that can also be opened to expose the growing medium and allow examination of the root system (fig. 2.1.13A). One operational drawback of these types of containers is that they must be assembled (fig. 2.1.13B) and placed in holding trays after they are purchased. When different

Figure 2.1.12—*Intense sunlight, especially ultraviolet radiation, can cause plastic containers to become brittle. Many containers are now constructed of plastics with "ultraviolet inhibiting" chemicals.*

container types are being evaluated, this added handling cost must be compared to the benefits of being able to monitor the condition of the growing medium and roots.

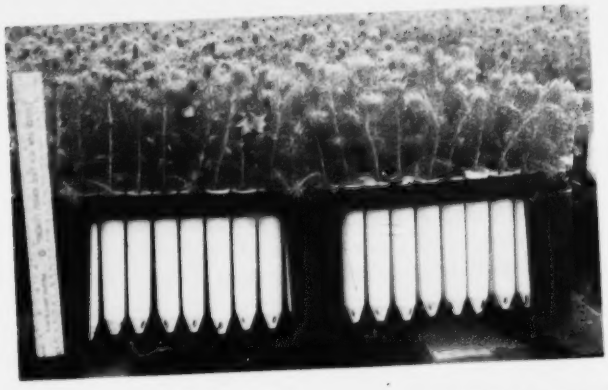
Ability to interchange and consolidate containers (unitization). One operational feature that has several management implications is unitization, in which individual containers fit interchangeably into a tray system. A typical example is the Ray Leach Single Cell® container (fig. 2.1.14A-B). One of the significant operational benefits of a unitized container system is that unwanted individual cells can be removed from the tray and replaced with others. This is particularly useful during thinning, when empty cells can be replaced with cells containing a germinant, and during rogueing, when diseased or otherwise undesirable seedlings can be replaced with cells containing healthy seedlings. Such consolidation can save a considerable amount of growing space in the greenhouse (fig 2.1.14C), and during storage and shipping. Unitized containers are also commonly used for tree improvement crops where each seedling needs to be individually handled and labeled. One drawback of the unitized container design is the additional handling required to reposition the individual cells in the tray if the seedlings are shipped to the outplanting site in the cells.

Handling, shipping, and storage. Containers must be handled repeatedly from initial shipping, through the growing season, to storage, shipping, and outplanting. Collapsible containers, such as the paperpot, are purchased in a compressed form and have lower shipping and presowing storage costs (Hoedemaker 1974); however, these same containers must be expanded before filling and sowing and thus require additional handling. The size and filled weight of a container will also affect ease of handling. Containers must be sturdy enough to withstand repeated handling. Automated handling systems also place mechanical stress on the containers and racks.

The type of shipping and storage system also needs consideration during container selection. If the seedlings are to remain in the container, then some sort of shipping box must be used to protect them during shipping and interim storage. Many container nurseries are extracting the plug seedlings from their growth containers and wrapping them in plastic bags or film for refrigerated storage and subsequent shipping to the planting site. Different types of containers require different handling equipment, and these factors may have a significant influence on the best type of container for a given nursery and associated planting system.

Figure 2.1.13—*Sleeve containers, such as this Tubepack®, are designed to allow examination of the growing medium and root growth during the growing season* **(A).** *These containers come in two matched sections, which must be assembled before use* **(B).**

A



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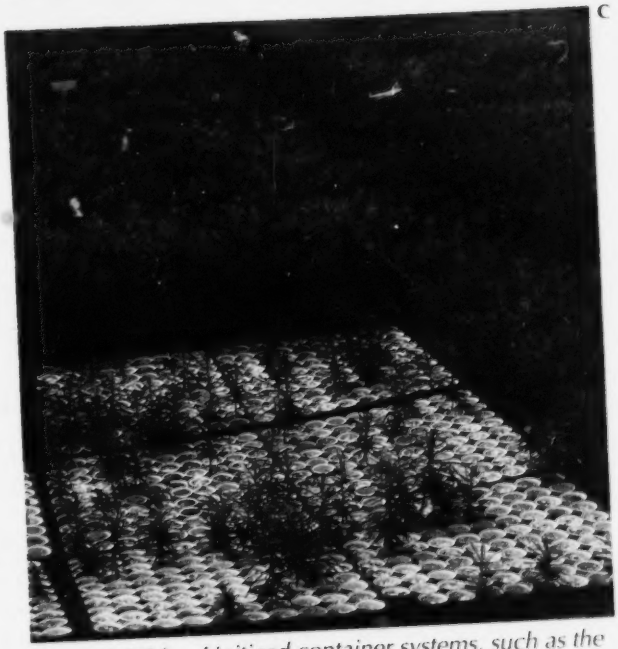

Figure 2.1.14— *Unitized container systems, such as the Ray Leach Single Cell®, consist of individual containers (**A**) that are interchangeable in a separate tray system (**B**). One practical feature of unitized containers is that they can be consolidated: cells that are empty or contain cull seedlings can be removed so that each space in the tray has a healthy seedling, thus optimizing the utilization of growing space. Trays in the foreground (**C**) contain cells that were removed from the now fully occupied trays in the background.*

2.1.3 Types of Containers

Container tree seedlings have been grown in many different types of containers over the years. Initially, standard horticultural containers were used, but nursery managers soon realized that woody plant seedlings required containers with special features, such as those discussed in the previous section. Many different types of containers have been tried but, after 2 decades of testing, only a relatively small percentage (28%) of the containers listed in "How to grow tree seedlings in containers in greenhouses" (Tinus and McDonald 1979) are still in use. New types of containers are still being designed and tested at the present time; this effort to develop the ideal container will undoubtedly continue because there is no single type of container that is perfect for all applications.

Although several different systems for categorizing containers have been used, the most practical system divides containers into two functional categories: those that are planted with the tree seedling, and those that are removed before the seedling is planted (Tinus and McDonald 1979).

2.1.3.1 Containers planted with the seedling

Much of the original work on developing containers for forest tree seedlings centered on designing a container that not only would grow an acceptable seedling in the nursery, but also could be directly outplanted in the field. Two different types of these containers were developed. Containers of the first type are made of a biodegradable material, such as molded peat moss or wood fiber (for example, peat sticks or fiber pots), that decomposes after outplanting. Seeds are sown on the top and the seedling roots penetrate through the container. The major problem with these biodegradable containers is that they lack a solid wall with antispiralling features so that seedling roots grow randomly, often into adjacent containers. Another drawback is that they often become covered with algae and mold in the nursery and thus difficult to handle. Barnett and Brissette (1986) reported that some biodegradable containers, notably the Kys-Tree-Start* produced acceptable southern pine seedlings and performed well in the field. Although some biodegradable containers are still available (table 2.1.4), none are currently in widespread use in North American container tree nurseries (table 2.1.1). These containers are probably useful only for growing seedlings for short periods before their root systems become too expansive.

The second type of biodegradable container consists of a shell of hard plastic, plastic mesh, or specially treated paper that is filled with growing media and sown with seed to produce a tree seedling under normal nursery culture. The tree seedling is then outplanted in the container, which theoretically would then expand, decompose, or somehow allow roots to grow out into the surrounding soil. Hard plastic containers that were designed to expand from root pressure after outplanting, for example, the Walters Bullet and Ontario tube (fig. 2.1.1), enjoyed some early successes (Walters 1974, Reese 1974), but there were problems with inconsistent root egress and some cases of root strangulation (Barnett and McGilvray 1981, Van Eerden 1982). Tree seedlings have also been successfully grown in plastic mesh containers, but some root restriction still occurred after outplanting (Budy and Miller 1984, Barnett and McGilvray 1981). Because of concern over such problems with root form after outplanting, interest in hard plastic or plastic mesh containers that can be outplanted with the seedling had declined by the time of the Container Nursery Survey (table 2.1.1).

One of the most successful containers that is still outplanted with the seedling is the paperpot (table 2.1.1), which was introduced in eastern Canada about 20 years ago to replace the Ontario tube. Barnett and Brissette (1986) concluded that the paperpot is the best container of this type. Paperpots are bottomless, hexagonally shaped paper tubes that are interconnected in a honeycomb-like design (fig. 2.1.15). They are constructed of a special paper, which is a mixture of easy decomposing paper and fibers that resist decomposition, and are available in three grades that resist decomposition for different lengths of time: **B** for 4 to 6 weeks, **V** for 7 to 9 weeks, and **F** for 3 to 12 months. Each individual paperpot is sealed with an insoluble glue to form a hexagonal, open-ended tube. Paperpots are interconnected to adjacent pots with a water-soluble glue that slowly breaks down during the nursery period so that the individual containers can be separated just before planting (fig. 2.1.15). The accordion-like sections of paperpots are shipped flat and must be expanded into a hard plastic tray before filling and sowing.

Several sizes of paperpots are available, but the 408 size was the most popular in North American container tree nurseries at the time of the Container Nursery Survey (table 2.1.1). One of the major concerns about paperpots is poor control of root form. Root spiralling and root growth between containers frequently occur (Barnett and

McGilvray 1981), and this characteristic is considered undesirable by many nursery managers and reforestation foresters. Barteaux and Kreiberg (1982), however, report that problems with root intergrowth between paperpots were "minimal," and that plantation checks have shown that paperpot container seedlings had better root form than bareroot seedlings. A newly developed product, the PS paperpot, is made of thin plastic containing a copper strip to eliminate rooting between containers during the nursery phase (Macdonald 1986). The Ecopot® is another new modification of the paperpot system that contains parallel plastic strips between the individual cells. This addition inhibits root growth between adjacent cells and produces a plug seedling that can be extracted from the container (Sims 1988).

The popularity of paperpots is strongly regional; in Canada, this container is very popular in central and eastern provinces but is rarely used in the West (Smyth and Ramsay 1982). Barteaux and Kreiberg (1982) compared paperpots to many other container types over a 10-year period in New Brunswick and found that paperpots were the least expensive and easiest to handle. Canadian container tree nurseries have recently shifted away from paperpots, however, because of concern about poor root egress after outplanting, especially on cold and wet sites (Sims 1988).

Table 2.1.4—*Listing of major types of containers currently available in the United States and Canada for growing forest tree seedlings*

	Construction material	Manufacturers/suppliers
Containers planted with seedling		
Paper containers		
Paperpot	Specially treated paper	Hakmet Ltd. PO Box 248 Dorion, PQ CANADA J7V 7J5 Lannen Inc. 880 Calle Plano, I PO Box 3383 Camarillo, CA 93011
Stretch-A-Pot®	Specially treated paper	Pan Agro 2084 North, 1200 East North Logan, UT 84321
Wood fiber containers		
Jiffy pot Forestry pellet	Molded peat moss Molded peat moss in plastic mesh	Jiffy Products of America 1400 Harvester Road PO Box 338 West Chicago, IL 60185 Jiffy Products Ltd. PO Box 360 Shippagan, NB CANADA E0B 2P0

Table 2.1.4 (continued)—*Listing of major types of containers currently available in the United States and Canada for growing forest tree seedlings*

	Construction material	Manufacturers/suppliers
Fiber pot	Molded wood pulp	Western Pulp Products Co. Box 968 Corvallis, OR 97339
Containers removed before outplanting		
Individual cells in trays		
Ray Leach Single Cell System®	Low-density polyethylene cell, with high-impact polystyrene tray	Stuewe and Sons, Inc. 2290 SE Kiger Island Drive Corvallis, OR 97333
Stuewe Super Cell®	Low-density polyethylene	Stuewe and Sons, Inc. 2290 SE Kiger Island Drive Corvallis, OR 97333
Hawaii dibble tube	High-density polyethylene cell, with high-impact polystyrene tray	Firewheel Manufacturing Co. Ltd. PO Box 72-41 Taipei, Taiwan Republic of China
Colorado container	High-impact polystyrene cell with an expanded polystyrene tray	Colorado Hydro, Inc. 5555 Ute Highway Longmont, CO 80501
Deepot®	High-density polyethylene cell and tray	J. M. McConkey & Co., Inc. PO Box 1690 Sumner, WA 98390 Stuewe and Sons, Inc. 2290 SE Kiger Island Drive Corvallis, OR 97333
Book or sleeve containers		
Spencer-Lemaire Rootrainer®	PET (polyethylene terephthalate) or ABS (acrylonitrile-butadienestyrene)	Spencer-Lemaire Industries, Ltd. 11413 120 Street Edmonton, AB CANADA T5G 2Y3 A.H. Hummert Seed Co. 2746 Choteau Avenue St. Louis, MO 63103
Tubepack®	Polystyrene	Porter-Walton Wholesale Nursery 262 West, 400 South Centerville, UT 84014

Table 2.1.4 (continued)—*Listing of major types of containers currently available in the United States and Canada for growing forest tree seedlings*

	Construction material	Manufacturers/suppliers
Block containers		
Styroblock®	Expanded polystyrene	Silvaseed Company PO Box 118 Roy, WA 98580 Beaver Plastics, Ltd. 12150 160 St. Edmonton, AB CANADA T5V 1H5
First Choice® block	Expanded polystyrene	First Choice Manufacturing 19402 56th Avenue Surrey, BC CANADA V3S 6K4 Stuewe and Sons, Inc. 2290 SE Kiger Island Drive Corvallis, OR 97333
Styrofoam® block	Expanded polystyrene	Plant-A-Plug Systems PO Box 1953 Pine Bluff, AK 71613
Colorado Styrofoam® block	Expanded polystyrene	Colorado State Forest Nursery Foothills Campus Colorado State University Ft. Collins, CO 80523
Ropak® Multi-pot seedling tray	High-density polyethylene	Sauze Technical Products Corp. 345 Cornelia Street Plattsburgh, NY 12901 Stuewe and Sons, Inc. 2290 SE Kiger Island Drive Corvallis, OR 97333 Ropak Can-Am Ltd. PO Box 340 Springhill, NS CANADA B0M 1X0
Hiko System® Containerset	High-density polyethylene	International Forest Seed Co. PO Box 290 Odenville, AL 35120

Table 2.1.4 (continued)—*Listing of major types of containers currently available in the United States and Canada for growing forest tree seedlings*

	Construction material	Manufacturers/suppliers
Deep Groove Tube Tray®	High-density polyethylene	Growing Systems, Inc. 2950 North Weil Street Milwaukee, WI 53212
Capilano seedling tray	High-density polyethylene	Capilano Plastics Co., Ltd. 1081 Cliveden Avenue Annacis Island New Westminster, BC CANADA V3M 5V1 Stuewe and Sons, Inc. 2290 SE Kiger Island Drive Corvallis, OR 97333
Todd® planter flat	Expanded polystyrene	Speedling Inc. Old Highway 41 South PO Box 7238 Sun City, FL 33586
Seedling tray	Expanded polystyrene	Castle and Cooke Techniculture, Inc. PO Box 1759 Salinas, CA 93902 Grow-Tech, Inc. 56 Peckham Road Watsonville, CA 95076
Ecopot	Plastic-laminated paper	Hakmet, Ltd. PO Box 248 Dorion, PQ CANADA J7V7J5 Lannen, Inc 880 Calle Plano, 1 PO Box 3383 Camarillo, CA 93011
Stretch-A-Pot	Polyethylene film	Pan Agro 2084 North, 1200 East North Logan, UT 84321

Table 2.1.4 (continued)—*Listing of major types of containers currently available in the United States and Canada for growing forest tree seedlings*

	Construction material	Manufacturers/suppliers
Separate containers		
Treepot	High-density polyethylene	Stuewe and Sons, Inc. 2290 SE Kiger Island Drive Corvallis, OR 97333 J.M. McConkey & Co., Inc. PO Box 1690 Sumner, WA 98390
Rootrainer® One Cell	PET (polyethylene terephthalate)	Spencer-Lemaire Industries, Ltd. 11413 120 Street Edmonton, AB CANADA T5G 2YE A.H. Hummert Seed Co. 2746 Choteau Avenue St. Louis, MO 63103
Polybag	Polyethylene film	HGP Inc. 761 Kanoelehua Avenue Hilo, HI 96720 A.H. Hummert Seed Co. 2746 Choteau Avenue St. Louis, MO 63103
Miniature containers		
Techniculture® plug system	Expanded polystyrene	Castle and Cooke Techniculture, Inc. PO Box 1759 Salinas, CA 93902
Miniblock® 448	Expanded polystyrene	Same as Styroblock distributors
First Choice Hahn 408	Expanded polystyrene	Same as First Choice block distributors
Used containers		Stuewe and Sons, Inc. 2290 SE Kiger Island Drive Corvallis, OR 97333

Paperpots have not fared well in the United States based on several nursery and field tests. Barnett and McGilvray (1981) tested paperpots with southern pines and found that the paper used in the Japanese paperpot degraded slowly after outplanting and did not allow root egress, resulting in lower field survival and field growth. Barnett and Brissette (1986) reported that the paper used in the Finnish paperpot allowed faster root egress than the Japanese paperpot. Budy and Miller (1984) found that Jeffrey pine seedlings had very poor outplanting survival and growth in the Japanese paperpot. Dirmarsen and Alm (1979) outplanted red and jack pine in Japanese paperpots in Minnesota and found that the paperpots had not degraded and that roots had not penetrated the paper after four growing seasons. One reason for this discrepancy between geographical regions may be due to climate or soil type. The outplanting sites in eastern Canada are probably wetter than those in the United States, and this higher soil moisture may hasten paper decomposition rate and root egress. Paper becomes impervious to root penetration if allowed to dry and so seedlings would become root-bound on dry outplanting sites.

One recent development in this container class is the Jiffy® forestry pellet, a modification of the Jiffy 7® horticultural peat pellet (Hatheway 1988). The forestry pellet utilizes a new type of plastic netting that tears apart as the roots grow out of the container. This new container is currently being used in the Maritime Provinces of Canada.

2.1.3.2 Containers removed before outplanting

Containers for producing seedlings that are extracted prior to outplanting (plug seedlings) were by far the most popular type (91% of total) in forest nurseries in the United States and Canada at the time of the Container Nursery Survey (table 2.1.1). The term **plug seedlings** results from the fact that their roots bind the growing medium together into a relatively firm mass or plug (fig. 2.1.16). Containers for producing plug seedlings should have two common characteristics (Tinus and McDonald 1979):

1. The walls of the container should be relatively smooth so that roots do not penetrate and make the plug difficult to remove.

Figure 2.1.15—*Paperpots consist of a series of interconnected paper cells that are arranged in a honeycomb pattern and can be separated before outplanting (courtesy of Lannen, Inc., Camarillo, CA).*

2. The cavity of the container should be tapered from top to bottom so that the seedling can be easily extracted from the top.

Individual cells in trays. An individual container that is part of a larger set of containers is termed a cell or tube. These cells or tubes are supported in a tray or rack, which determines the spacing of the cells and therefore seedling growing density (Allison 197). Although the term rack is more descriptive, the term tray will be used here because it is the more commonly used in the forest nursery trade.

Although there are several types of individual cell containers available (table 2.1.4), the Ray Leach (R/L) Single Cell® system is the most common in North American container tree nurseries, constituting 16% of total container use at the time of the Container Nursery Survey (table 2.1.1). Several different sizes of R/L Single Cells are available, and each consists of a soft plastic tube that fits in a hard plastic tray (fig. 2.1.14). The capacity of the various cells ranges from 49 to 164 cm^3 (3.0 to 10.0 cubic inches), and the growing density ranges from 500 to 1,076 cells/m^2 (49 to 100 per square foot) (table 2.1.1).

One of the biggest advantages of the individual cell system is that the containers can be handled either separately or collectively. This unitization feature allows consolidation of individual cells during culling, so that greenhouse growing space can be used efficiently (fig. 2.1.14). Seedling growing density can also be expanded by placing cells in every other location, which promotes larger seedlings and also decreases foliage diseases by encouraging air circulation around the seedling. After firm root plugs have formed, seedlings can be removed from the containers by gently squeezing the container or tapping the top of a cell on a hard surface. One disadvantage of the individual cell system is that the containers have to be replaced in the tray if the cells are removed for shipping or cleaning between crops (Tinus and McDonald 1979). The hard plastic trays of the R/L Single Cell system are relatively fragile and easily damaged if they are repeatedly handled while loaded with heavy seedlings. With the current trend towards extraction of shippable seedlings from the containers at the nursery, however, this is becoming less of a problem.

R/L Single Cells are most popular in the Northwestern United States (Landis 1982), where they were developed. They and the other types of single cell systems are also used at scattered nurseries around the country and are especially popular at nurseries specializing in tree improvement stock. Another individual cell container, the dibble tube, is similar to the R/L Single Cell except that it was specifically designed to grow tropical species; the dibble tube is currently being used in Hawaii, Guam, and several foreign countries.

Extruded peat cylinders are another type of individual container. They are formed by extruding a peat-water mixture into a continuous, thin plastic casing; the filled casing is then sliced into uniform cylinders or "sausages." While conifer seedlings were successfully grown in these containers, they have never been used extensively in North American container tree nurseries (Mitchell and others 1972, Hocking and Mitchell 1975).

Figure 2.1.16—*Container seedlings that are removed from the container before outplanting are called plug seedlings because their root systems bind the growing medium together into a cohesive plug.*

Other types of individual cell containers, such as the polytube or polybag (fig. 2.1.17), are constructed of plastic film. These containers are inexpensive and easy to ship and store and are popular in nurseries in developing countries or remote locations. Several different sizes of polybags are commercially available; the 20 x 15 cm (8 x 6 in) size was found to produce better quality casuarina seedlings (Vinaya Rai and Natarajan 1987). Polybags come in clear and black plastic, but black polybags have proven to be superior because they retard the growth of algae (Liegel and Venator 1987). Proper root development is a problem in these containers because their smooth sides promote root spiralling and root balling is common in the bottom of the container (Venator and others 1985). Wilson (1986) evaluated the

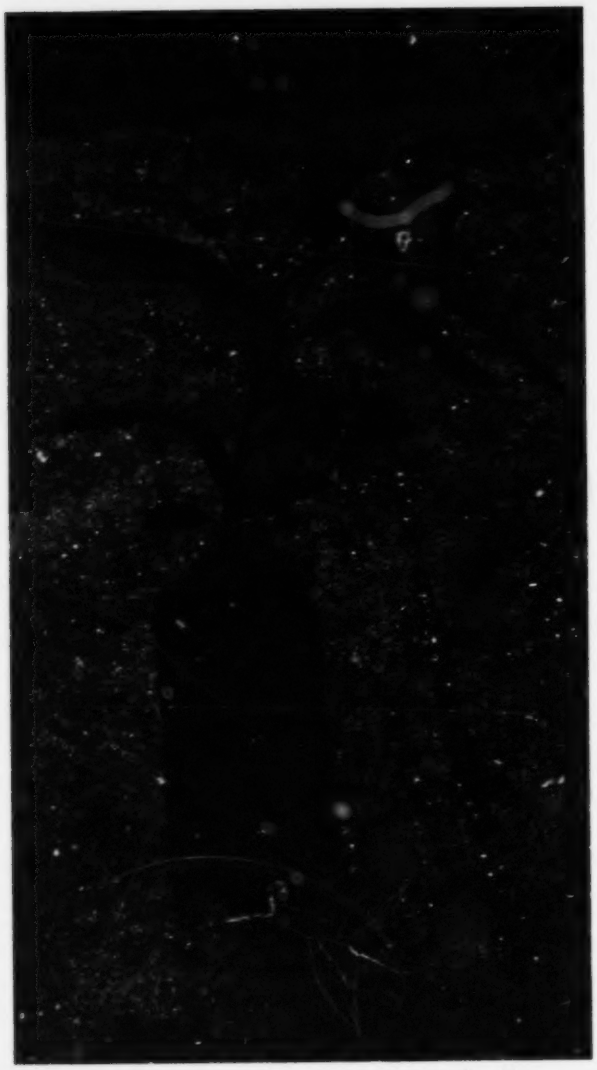

Figure 2.1.17—*The polybag is an individual cell container that has been popular in nurseries in less industrialized countries; it does not prohibit root spiralling or allow air pruning, however.*

use of polybags and polytubes in tropical nursery culture, and concluded that their popularity was more a function of the hardiness of the seedlings being grown than in the beneficial attributes of the container system. Sharma (1987) discussed the use of polybags in tropical nurseries and the causes of root deformation, and listed some cultural practices that reduce root problems.

Book and sleeve containers. This container type consists of a row of cells made of relatively thin plastic, and is designed to be opened and closed without damaging seedling roots. About 10% of the containers used in forest nurseries in the United States and Canada at the time of the Container Nursery Survey were book or sleeve containers (table 2.1.1). The original and most popular of these containers is the Spencer-Lemaire (S/L) Rootrainer® (fig. 2.1.18), which is called a book container because it consists of two matched forms that are hinged together on the bottom and produce a row of rectangular cells when snapped together. A sleeve container consists of two matched sections that are independent but snap together to form a row of cells when assembled (fig. 2.1.13). Once assembled, book and sleeve containers are held together in specially designed trays or taped together to form blocks of cells.

Book and sleeve containers are available from several distributors in the United States and Canada (table 2.1.4). Rootrainers come in a variety of sizes, and the most popular sizes range in cell capacity from 40 to 350 cm^3 (2.5 to 21.5 cubic inches) and in cell density from 516 to 1,280 cells/m^2 (48 to 119 per square foot) (table 2.1.1). A new, large capacity S/L container (1,300 cm^3 or 80 cubic inches) has been recently developed that has a growing density of 172 cells/m^2 (16 per square foot).

Both book and sleeve containers are tapered and have well-defined vertical ribs that discourage root spiralling and guide roots to the drainage hole at the bottom of the container. One very practical feature is that they can be easily opened up to check the condition of the growing medium and root growth at any time during the growing cycle, even before a firm plug has developed (fig. 2.1.7 and 2.1.13A). The durability of these containers depends on the type of plastic: the original polystyrene containers tended to breakdown in sunlight and could only be used for a couple of years. For extended use, the newer model Rootrainer constructed of ABS (acrylonitrilebutadiene-styrene copolymer) plastic is considerably more durable. Another advantage is that the plugs are easily extracted

Figure 2.1.18—*Book or sleeve containers consist of two matched sections of molded plastic that fit together to form a row of rectangular cells. These Spencer-Lemaire Rootrainers® are book containers that are assembled and then placed next to each other in a holding tray to form a block (courtesy of Spencer-Lemaire Industries, Ltd., Edmonton, Alberta, Canada).*

for grading and packing. Book and sleeve containers are somewhat less durable than some of the other container types, and individual cells cannot be removed if they fail to produce a germinant or contain a diseased seedling. Because they are easily opened, however, empty cavities can be filled with other seedlings once they have formed a firm plug (Tinus and McDonald 1979).

Because the S/L Rootrainer was originally developed in Alberta, Canada (Spencer 1974), it is popular in that region, as well as other Canadian provinces (Smyth and Ramsay 1982, Kelly 1982). In the United States, both the S/L Rootrainer and sleeve containers are used at various locations around the country with no strong regional pattern.

Block containers. Block containers consist of a block, generally rectangular, that contains a number of cavities or cells arranged in a regular pattern (fig.2.1.19 and 2.1.20). The individual cells are cylindrical cavities that gradually taper from the top opening to the drainage hole at the bottom. Block containers were the most popular container type in use at the time of the Container Nursery Survey, and several brands and sizes are commercially available (table 2.1.4). In North America, the most common block containers are the Styrofoam® block (fig. 2.1.19) and the Multi-Pot® (fig. 2.1.20), which made up 51 and 11% of container use at the time of the Container Nursery Survey, respectively (table 2.1.1).

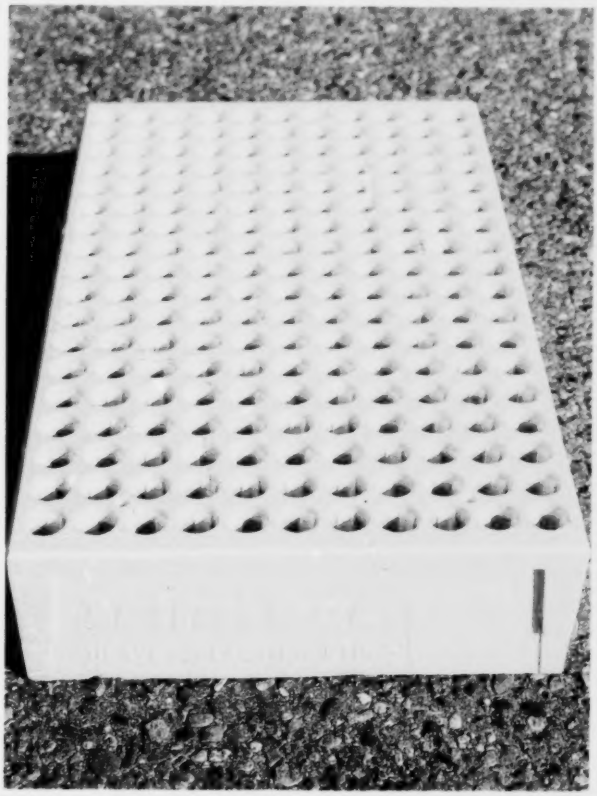

Figure 2.1.19—*Styrofoam® blocks are made of expanded polystyrene foam and contain cylindrical cavities or cells that are arranged in a regular pattern.*

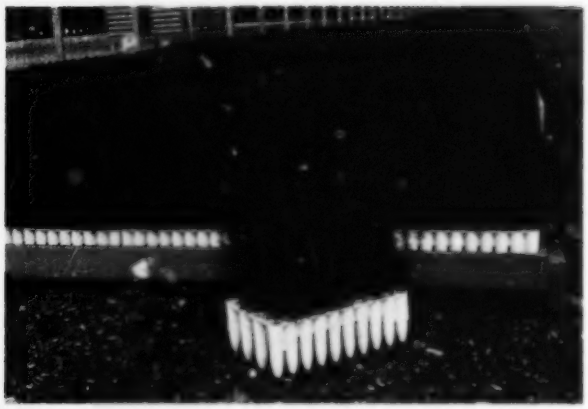

Figure 2.1.20—*The Multi-pot® container is a molded hard plastic block with cylindrical cells arranged in alternate rows (courtesy of Ro-Pak, Inc., Springhill, Nova Scotia, Canada).*

Block containers are single, lightweight units that are easy to handle and have no individual cells or sleeves of cells that can become dislodged. Many of the Styrofoam blocks and Multi-pots with different cavity sizes have standard outside dimensions so that they can be used with the same filling, sowing, handling, and extraction equipment (Tinus and McDonald 1979). This feature is also useful during storage, because the Styrofoam blocks stack easily and the Multi-pots will nest together. Both types of block containers are resistant to breakdown in sunlight and are reusable; Multi-pots claim an operational life of 6 to 10 years. A new liquid coating, Speedling® Super-Cote, can be applied to Styrofoam blocks to extend their life expectancy. It has been used successfully on several southern pine seedlings, and reportedly makes the plugs easier to extract. Root control ribs inside the cavity are also standard on both types of block containers, although Barnett (1982) reported that roots of loblolly pine seedlings were deformed at the bottom of the plugs because the anti-spiral ribs did not extend all the way to the bottom of some Styrofoam block cavities. One of the drawbacks of all types of block containers is that empty cavities cannot be replaced, making high seed quality and proper sowing procedures necessary.

Styrofoam blocks are composed of expanded polystyrene foam and come in a wide variety of container capacities, ranging from 41 to 492 cm^3 (2.5 to 30.0 cubic inches), and growing densities ranging from 270 to 1,108 cells/m^2 (25 to 103 per square feet). It is worth noting that environmentally polluting chloro-fluorocarbons are not used in the manufacturing of Styrofoam blocks.

Styroblocks® are one specific brand of Styrofoam block, and the term should not be used as a generic term for all Styrofoam containers.

An important characteristic of Styrofoam blocks is their inherent insulating value, which protects seedling root systems against extreme temperatures. One cultural problem with Styrofoam containers is that roots of some species grow into the pores in the cavity walls, making the seedlings difficult to extract and the blocks difficult to clean and sterilize between crops. A new Styrofoam block, called the Ventblock®, offers a series of ventilation holes between the cavities to promote air circulation between seedlings; this feature has proven effective in controlling the grey mold fungus (*Botrytis cinerea*) which thrives in the humid environment in densely growing seedlings (Peterson and Sutherland 1989).

Multi-pots are composed of high-density polyethylene and are available in a range of sizes, although only the 57 and 65 cm^3 (3.5 and 4.0 cubic inches) were commonly used in the United States and Canada at the time of the Container Nursery Survey (table 2.1.1). Multi-pots are one of the most durable containers that are currently available, and their smooth inner cell walls facilitate seedling extraction and make cleaning and sterilizing between crops easy.

The Ecopot® is another block container that is a modification of the paperpot system. This container resembles the paperpot in the way it is bought and used, but contains parallel plastic strips in between the individual cells. These plastic strips are removed one row at a time during packing, producing a plug seedling. For nurseries that already have the paperpot sowing and handling system, the Ecopot is an inexpensive way to shift to a plug seedling system (Sims 1988).

Block containers have a regional usage pattern in Canada: they are most popular in the provinces where they were originally developed. Styrofoam blocks are most popular in British Columbia, and Multi-pots are gaining increasing popularity in the Maritime Provinces (Smyth and Ramsay 1982) and the southern United States. In the United States, Styrofoam blocks are one of the most common containers in the Northwest (Landis 1982), and about 80% of the container seedlings produced in the Lake States come from Styrofoam blocks (Alm 1982). Barnett (1982) reports that southern pine seedlings grew well and also had good outplanting performance when produced in Styrofoam blocks.

Miniature containers. A recent innovation in the container tree nursery industry, borrowed from the vegetable transplant industry, is the use of very small containers (mini-containers) to produce young plug seedlings for container/bareroot transplants (Hee and others 1988, Klapprat 1988). Seedlings are produced in rectangular plastic or Styrofoam containers (fig. 2.1.21A), that contain a grid of small cells [4 to 18 cm^3 (0.25 to 1.1 cubic inches)] and produce high seedling growing densities [948 to 3,813 cells / m^2 (88 to 354 per square foot)]. After a relatively short growing period in a greenhouse, the container seedlings are transplanted to bareroot nursery beds for an additional period of growth. Although a number of different miniature container systems are on the market, two of the most commonly used in container tree nurseries in North America are the Mini Plug® system (Hee and others 1988), and the Techniculture® plug system (Klapprat 1988).

The objective of the mini-container system is to produce a fully extractable seedling with a dimensionally stable root plug that will tolerate transplanting within a relatively short growing period (3 to 4 months) (fig. 2.1.21B). Both the Mini-plug and Techniculture systems are fully automated, from sowing the seed through transplanting. Because the seedlings grow in them for only a short time, mini-containers are radically different from typical container types: the cells are very short and closely spaced, and do not have ribs to control root spiralling. In some systems, the mini-containers are carried to the bareroot nursery where they are used as magazines for feeding the seedlings to the transplanter; other nurseries extract the seedlings before transplanting.

The future of miniature container systems appears promising. They can be used to shorten the rotation for slow-growing species or species that do not grow well in bareroot nurseries. Because all transplants are relatively more expensive than seedlings, economic analyses and outplanting trials of mini-container transplants are currently being performed. A series of trials with the Mini-plug system showed that the container transplants performed as well or better than traditional bareroot seedling or transplant stock types on a variety of coastal sites in the Pacific Northwest (Tanaka and others 1988).

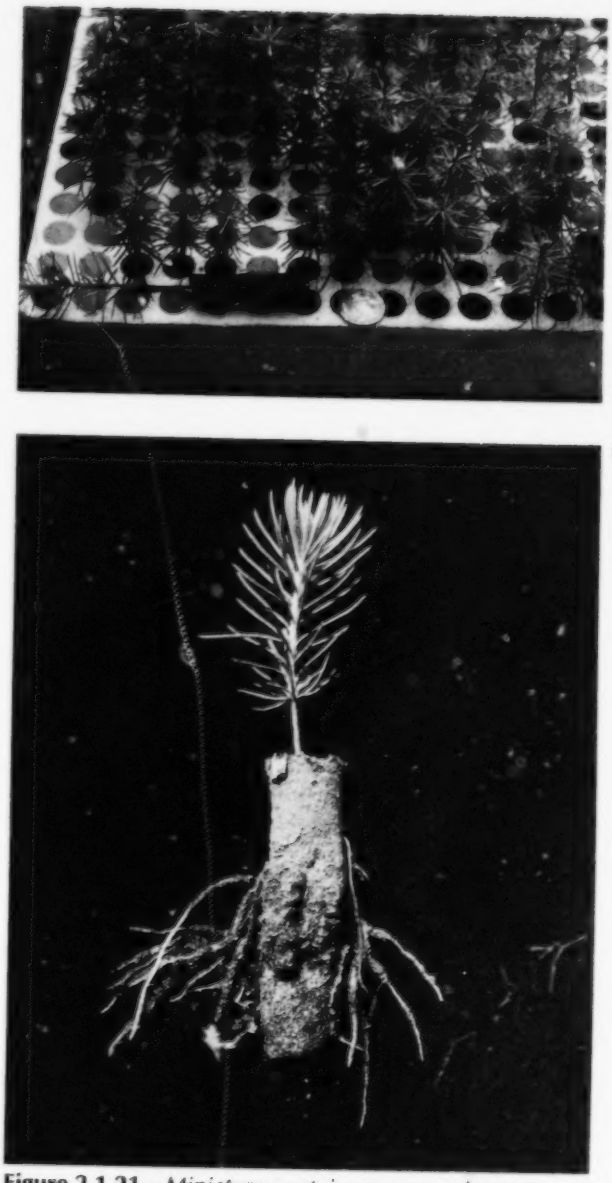

Figure 2.1.21—*Miniature containers are used to grow small seedlings* **(A)**, *which are then transplanted to bareroot beds when only a few months old to produce plug + one transplants. The spruce seedling in* **(B)** *had only been transplanted for a few weeks, and already shows new roots growing out of the plug.*

2.1.4 Chemical Root Pruning

There has been widespread concern over the root form of container seedlings and the potential problems with root-bound plug seedlings after outplanting. Burdett and others (1986) relate the problem of physical instability (toppling) of lodgepole pine seedlings in British Columbia plantations to poor lateral root egress after outplanting, and discuss chemical and mechanical root pruning treatments to overcome this problem. Carlson and others (1980) studied the root system morphology of Sitka spruce that had been direct-seeded, or grown as bareroot or container seedlings, and concluded that the root deformation that was caused by outplanting was probably not severe enough to cause instability or growth retardation. Obviously, species rooting characteristics, type of planting tool, and soil characteristics on the outplanting sites have a significant effect on the root form of the seedling after outplanting. Nevertheless, container nursery managers and reforestation foresters are interested in any cultural treatment that will generate a better root system in container tree seedlings.

One option is to coat the interior walls of the containers with chemicals that inhibit root growth, such as cupric carbonate ($CuCO_3$) or indolebutryic acid (IBA), carried in a binding material such as latex paint (Pellett and others 1980, McDonald and others 1984a). Chemicals for root pruning must inhibit root growth and remain in the application zone throughout the growing season without diffusing into the growing medium or becoming phytotoxic to the seedling. These chemicals must also not be toxic to nursery personnel or the environment (Hulten 1982). Tinus (1987) tested a variety of heavy metals including copper, silver, cobalt, nickel, lead, zinc, and antimony and found that only copper would stop root growth without injuring the seedling. $CuCO_3$ has been the most popular root pruning chemical used in subsequent trials, and recommended application rates range from 50 to 200 g/liter (2.0 to 6.7 ounces per gallon) depending on seedling species and container type (Wenny and others 1988).

Chemicals for root pruning can be either sprayed into the container cavities or used as a dip for the entire block. The blocks are then filled and sown in the usual manner, but when the seedling roots contact this chemical barrier they cease growing and suberize (fig. 2.1.22). New lateral roots are generated and are subsequently pruned when they reach the treated container wall, resulting in a more fibrous, branched root system that is evenly distributed throughout the container. These pruned root tips resume normal root growth when the seedling is removed from the container, creating a more natural, branched root system after outplanting (Burdett and others 1983, McDonald and others 1984a).

Burdett and Martin (1982) treated the inside of Styrofoam block containers with latex paint containing $CuCO_3$ and grew 10 different species of conifer seedlings in them (fig. 2.1.23). They reported that this chemical root pruning prevented root spiralling, but their results varied with seedling species, container volume, type of growing medium, and the concentration of $CuCO_3$ in the wall coating. McDonald and others (1984a) found that both $CuCO_3$ and IBA arrested root growth of ponderosa pine seedlings when applied to container walls, but the copper treatment was more effective. Romero and others (1986) reported that treatment with $CuCO_3$ significantly increased the number of lateral roots and both root and shoot weight in Caribbean pine container seedlings. Green ash and red oak seedlings grown in $CuCO_3$-treated containers were larger than controls and had more fibrous and evenly distributed root systems (Arnold and Struve 1989). Dong and Burdett (1986) reported that treating paper contain-

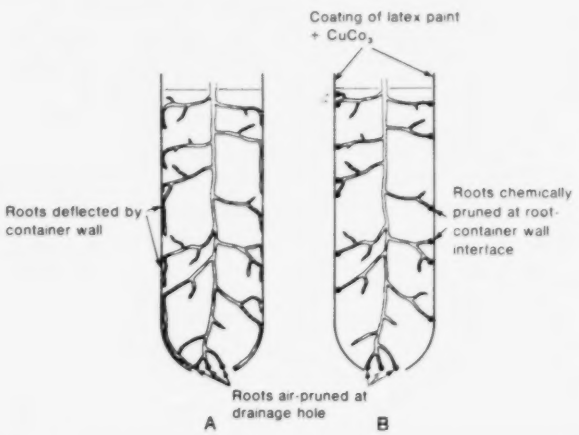

Figure 2.1.22—*Chemical root pruning involves treating the interior container wall with a growth-inhibiting chemical, such as cupric carbonate ($CuCO_3$). In an untreated container* **(A),** *roots are deflected downward until they are air-pruned at the drainage hole. The chemical barrier in a treated container* **(B)** *causes the lateral roots to be chemically pruned at the container wall. These pruned laterals become suberized but will begin to grow again after outplanting, resulting in a more natural, well-distributed root system (after Ruehle 1985).*

Figure 2.1.23—*Chemically root-pruned seedlings (left of each pair) of four different conifers produce a much more fibrous and well-balanced root system after outplanting compared to normal container seedlings (right of each pair) (from left to right: Pacific silver fir, Douglas-fir, western redcedar, and western hemlock) (courtesy of Burdett and Martin 1982).*

ers with cupric sulfide (CuS) prevented root spiralling in paper containers with a polyethylene coating and also stopped root growth between non-polyethylene-coated paper containers. Root distribution within the container has often been a problem, with the majority of new root tips forming at the drain hole at the bottom of the container. Copper-treated containers produced more new roots in the middle and upper zones of the container, which should promote better seedling stability after outplanting (Wenny and others 1988).

Chemical root pruning has also been found to have other benefits for container tree seedlings. Romero and others (1986) analyzed root development of $CuCO_3$-treated Caribbean pine seedlings and found that treated seedlings had more lateral roots as well as significantly larger stem diameters than control seedlings. They also noted that the $CuCO_3$ treatment caused a change in root morphology: treated seedlings had finer, more fibrous root systems than did untreated seedlings. Ruehle (1985) studied the effect of $CuCO_3$ on the root morphology of southern pine seedlings and found few significant differences in shoot or root dimensions, weight, or ectomycorrhizal formation. McDonald and others (1984b) found that a combination of $CuCO_3$ treatment and inoculation with ectomycorrhizal fungi increased the number of short roots of lodgepole pine seedings, and ectomycorrhizal formation on both lodgepole pine and ponderosa pine seedlings. Donald (1986) reported that copper salts also kept bryophytes from growing on the containers.

The real benefits of chemical root pruning should occur after outplanting, and results have generally been favorable. Green ash and red oak seedlings transplanted from containers treated with $CuCO_3$ had higher root growth potential compared to the controls; Arnold and Struve (1989) attributed this to the greater number of root tips produced after chemcal root pruning. McDonald and others (1984a) planted $CuCO_3$-treated ponderosa pine seedlings in vermiculite, and found that treated seedlings had 3 times more root egress and were also significantly taller than untreated seedlings. Burdett and others (1983) studied the root development of chemically pruned lodgepole pine seedlings after outplanting and found that treated seedlings have more uniform root growth (fig. 2.1.24) and significantly better height growth than controls. However, seedlings of three western conifer species, when examined 3 years after outplanting, showed no significant increase in survival or growth

Figure 2.1.24—*Four years after outplanting, the untreated lodgepole pine seedling (left) had fewer and smaller new roots than the chemically pruned lodgepole pine seedling (right) (courtesy of Burdett and others 1983).*

even though the seedlings did have more new roots in the upper zones of the soil (Wenny 1988). The practical benefits of chemical root pruning may only become obvious when the outplanted seedlings are exposed to physical or environmental stresses.

Although the use of copper-treated containers has not been implemented operationally in North America, chemical root pruning is currently being used in South Africa (Donald 1986); containers are dipped in a polymer suspension of Cu^{2+} ions called Styrodip prior to filing and sowing (Nelson 1989). Beaver Plastics has recently introduced the Trimroot Styroplug®, which uses a "differential coating" system (fig. 2.1.25) to control and prune roots within a Styrofoam container; they stress that operational trials are needed to test this new system, however. Another option is to stimulate natural air pruning of roots around the periphery of the plug by designing a container with air slits at regular intervals on the sides. The Rootmaker® container incorporates a series of drainage slots around the perimeter but is currently available in only one relatively large size (Whitcomb 1988).

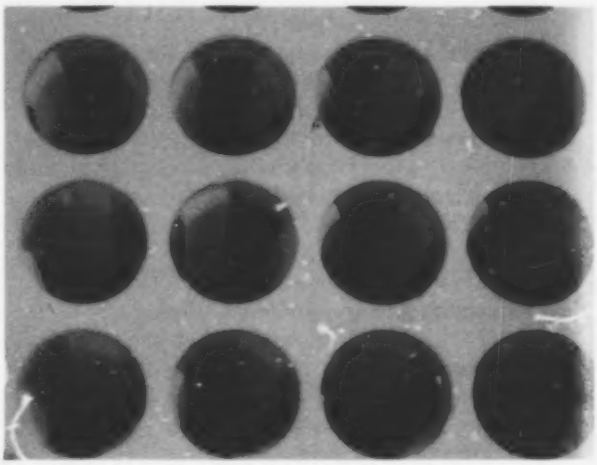

Figure 2.1.25—*The Trimroot Styroplug® features container cavities that have been treated with $CuCO_3$ to promote chemical root pruning.*

2.1.5 Conclusions and Recommendations

As evidenced by the variety of containers that are currently in use in container tree nurseries, acceptable seedlings can be produced in many different types of containers. There is no one container that exhibits all the many different characteristics, and thus, no single type of container is best for all nurseries and outplanting sites. In the final assessment, the choice of a container system depends on the objectives and cultural characteristics of each individual container tree nursery operation (Landis 1982).

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The Container Tree Nursery Manual

Volume Two Containers and Growing Media

Chapter 2 Growing Media

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2.2.1 Introduction

2.2.1.1 Terminology

Many different terms have been used for the **artificial soil** used in container nursery culture, including **potting soil, potting mix, soil mix, compost**, and **growth medium.** It is inappropriate to use the term **soil** when referring to these materials, however, because soil is rarely a component of growing media in container tree nurseries in the United States and Canada. The term **mix** is sometimes used because many of these materials are composed of several different components, although some forest nurseries use only one material—for example, peat moss—as a growing medium. To avoid confusion and remain consistent, therefore, the terms **growing medium** (singular) and **growing media** (plural) will be used throughout this manual because they are the most appropriate terms and least likely to cause confusion. The aqueous solution absorbed by and surrounding the growing medium particles will be called the **growing medium solution** or **medium solution**.

2.2.1.2 The need for "artificial soil"

When people first began to grow plants in containers, they used ordinary field soil but soon found that this practice created cultural problems. The very act of placing soil in a container produces horticultural conditions that are different from those of unrestricted field soil.

Restricted volume. Plants growing in containers have access to a very limited amount of growing medium compared to field-grown plants (Swanson 1989). Forest tree seedlings, in particular, are grown in small-volume containers, ranging from as small as 40 to over 700 cm^3 (2.5 to 45 cubic inches). This limited rooting volume means that seedlings have only small reserves of available water and nutrients and that these essential resources can change quickly (Van Eerden 1974).

Perched water table. By their very nature, containers create a perched water table because water cannot drain freely from the bottom of the container (Swanson 1989). The layer of saturated growing medium created at the bottom of the container has profound effects on the physical and horticultural properties of growing media. (See chapter 2, volume four of this manual.)

Imbalance of soil microorganisms. Native soils contain myriad microorganisms, some beneficial and some pathogenic. These organisms exist in a natural state of balance in field soils, but when these soils are placed in containers in the favorable growing environment of a greenhouse, many problems can develop. The high-fertility, high-moisture regimes used to promote rapid seedling growth favor the development of pathogenic organisms, such as damping-off fungi, but do not favor growth of most beneficial mycorrhizal fungi.

Lack of soil structure. Texture (particle size) and structure (particle aggregations) are basic physical properties of soil that create porosity. Although a given growing medium has texture, based on the size of the various component particles, the concept of soil structure does not apply to artificial growing media because the individual particles of the various components do not bind together. The regular cultivation program and organic amendments that farmers use to maintain favorable structure **(tilth)** in field soil are obviously impossible in container nursery culture. Therefore, the textural properties of growing media components must be carefully chosen and blended to produce the right mixture of porosity that will persist over the growing cycle.

2.2.1.3 History of artificial growing media

Because of the problems with field soil in containers, growers began supplementing soil with other materials to develop a mixture that would be suitable for container culture. The first systematic search for a uniform, standardized growing medium began in England in the 1930's when the John Innes Horticultural Institute developed a loam-based compost that was amended with peat moss, sand, and fertilizers (Bunt 1988). By the early 1950's, the first truly artificial growing media were created at the University of California; they were composed of various proportions of fine sand and peat moss with supplemental fertilizers (Matkin and Chandler 1957). The Cornell Peat-Lite Mixes, the predecessors of modern growing media, were developed at Cornell University in the 1960's using various combinations of peat moss, vermiculite, and perlite (Mastalerz 1977).

2.2.2 Functions of a Growing Medium

Plants growing in containers have certain functional requirements that must be supplied by the growing medium (Mastalerz 1977).

2.2.2.1 Water

Plants require a large, continuous supply of water for growth and other physiological processes, such as transpirational cooling, and this water must be supplied by the growing medium. Liquid water is held both externally and internally by the growing medium until it is needed by the seedling: externally in the relatively small pores between the particles and internally in the interior space of porous materials like peat moss. Because of the limited volume of small containers, the growing medium must have a high water-holding capacity to supply water to seedlings from one irrigation to the next.

2.2.2.2 Air

Plant roots consist of living tissue and must expend energy for growth and physiological processes, such as absorption of mineral nutrients from the medium solution. The energy for these physiological activities is generated by aerobic respiration, which requires a steady supply of oxygen. The byproduct of this respiration is carbon dioxide, which can accumulate to toxic levels if it does not disperse to the atmosphere. Therefore, growing media must be porous enough to provide efficient exchange of oxygen and carbon dioxide. Because oxygen diffuses through water only 1/10,000 as fast as through air, this gas exchange must take place in the larger, air-filled pores in the growing medium. These large pores are a direct function of media particle size, arrangement, and amount of compaction.

2.2.2.3 Mineral nutrients

With the exception of carbon, hydrogen, and oxygen, plants must obtain all 13 essential mineral nutrients from the growing medium solution. Many mineral nutrients, including the ammonium form of nitrogen (NH_4^+), potassium (K^+), magnesium (Mg^{2+}), and calcium (Ca^{2+}), exist in the growing medium solution as electrically charged cations. These nutrient ions remain in the medium solution until plant roots take them up and utilize them for growth and tissue maintenance or, because of their positive electrical charge, they become adsorbed onto negatively charged sites on certain types of growing medium particles. This supply of adsorbed nutrients, which is measured by the **cation exchange capacity** (CEC), provides a reservoir of mineral nutrients to support plant growth between fertilizer applications.

2.2.2.4 Physical support

The final function of the growing medium is to anchor the seedling in the container and support it in an upright position. This support is a function of the bulk density (relative weight) and the rigidity of the growing medium. Weight is important for large, individual containers that stand alone (Maronek and others 1986) but is inconsequential for the small-volume, aggregated container types that are typically used in forest tree nurseries. The rigidity of a growing medium is a function of the compressibility and compaction of the growing medium particles, and the size of the container.

2.2.3 Characteristics of an Ideal Growing Medium

There is no single growing medium that can be used for all purposes, but lists of general horticultural properties are provided by Hartman and Kester (1983), James (1987), and Swanson (1989). For container tree nurseries, a well-formulated growing medium will have most of the following properties, which can be separated into cultural characteristics (those that influence seedling growth) and operational characteristics (those that affect nursery operations).

2.2.3.1 Characteristics relating to seedling growth

The cultural characteristics of a growing medium are the properties that affect its ability to consistently produce crops of healthy tree seedlings under the cultural practices in a container tree nursery: slightly acid pH, high cation exchange capacity, low inherent fertility, adequate porosity, and freedom from pests.

Slightly acid pH. pH is a measure of relative acidity or alkalinity of a substance, on a logarithmic scale from 0 to 14; values below 7.0 are acidic and values above 7.0 are alkaline. Materials used to formulate growing media can differ considerably in pH. Peat mosses are usually acidic in nature, depending on the constituent plant species and local water quality, whereas vermiculite can range from neutral (pH 7.0) to mildly alkaline (Bunt 1988). pH ranges for the four principal growing media components used in container tree nurseries are listed in table 2.2.1. The final pH of a growing medium will depend on the proportion of the ingredients, their original pH, and subsequent cultural practices, especially fertilization and irrigation. Irrigation water is usually circumneutral or slightly alkaline, and so a normally acidic growing medium will typically rise 0.5 to 1.0 unit of pH (that is, become more alkaline) through the growing season (Gladon 1988).

The principal cultural effect of pH in mineral soils is its influence on availability of mineral nutrients, especially micronutrients; several mineral nutrients can become unavailable or even toxic at extreme pH values. Comparison of the effect of pH on the mineral nutrient availability of mineral and organic soils (such as most growing media) shows that maximum availability for organic soils is one full point lower (pH 5.5) than for mineral soils (pH 6.5) (fig. 2.2.1). Control of pH is less critical in container nurseries, where all essential mineral nutrients can be supplied with fertilization. Most plants can grow within a relatively wide range of pH values if micronutrients are supplied in the proper form and in the proper ratio (Bunt 1988).

The pH can also affect the numbers and types of microorganisms in growing media, including fungal pathogens. *Fusarium* spp. are more virulent in neutral to alkaline conditions, and losses to damping-off fungi increase at pH values above 5.9 (Handreck and Black 1984). Most of this information applies to native soils, however, and less is known about the effects of pH on pathogen activity in artificial growing media. One recent study on a root disease of Douglas-fir container seedlings revealed that disease losses were more severe at pH 4.0 (94%) than at pH 5.0 (10%) or pH 6.0 (4%) (Husted 1988).

On an operational basis, therefore, container nursery managers should strive to maintain the pH of their growing media in the slightly acidic range of pH 5.5 to 6.5. (See chapter 1 in volume four of this manual for a more detailed discussion.)

Table 2.2.1—*Characteristics of various components of growing media*

Medium component	Dry bulk density (kg/m³)	pH range	Mineral nutrients	Sterility	Cation exchange capacity	
					Weight (meq/100 g)	Volume (meq/100 m³)
Sphagnum peat	96.1—128.2	3.5—4.0	Minimal	Variable*	180.0	16.6
Vermiculite	64.1—120.2	6.0—7.6	K-Mg-Ca	Yes	82.0	11.4
Perlite	72.1—112.1	6.0—8.0	None	Yes	3.5	0.6
Pine bark	128.2—448.6	3.3—6.0	Minimal	Variable*	52.6	15.3

* Some peat sources have tested positive for pathogenic fungi, whereas other types of sphagnum peat and composted bark have been shown to contain beneficial organisms that can effectively suppress disease.

Source: adapted from Biamonte (1982).

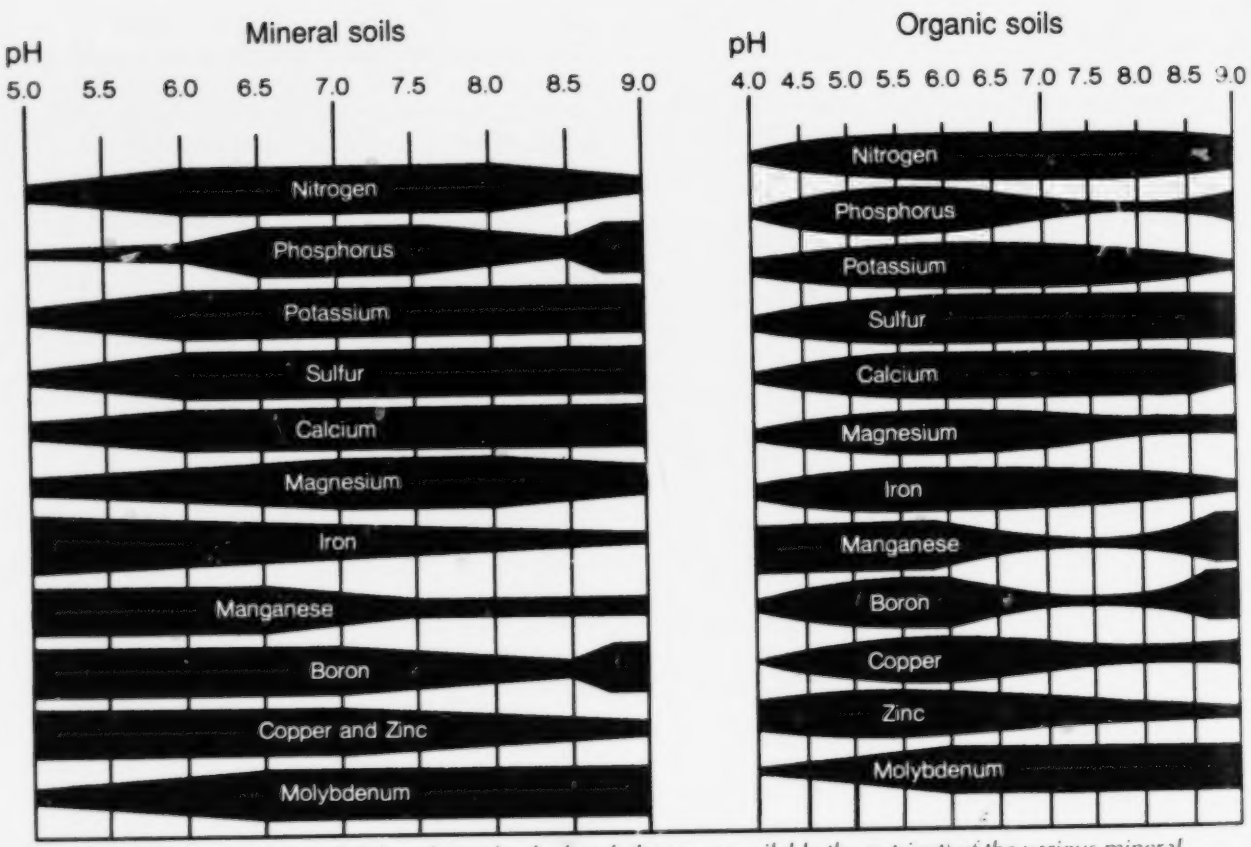


Figure 2.2.1—*The relative availability (the wider the band, the more available the nutrient) of the various mineral nutrients is different for mineral-based and organic-based soils. Maximum nutrient availability for mineral soils is pH 6.5, compared to 5.5 for organic soils (Kuhns 1985).*

High cation exchange capacity. The ability of a material to adsorb positively charged ions, the **cation exchange capacity** (CEC), is one of the most important factors affecting the fertility of growing media. The CEC can be defined as the sum of the exchangeable cations, measured in units called **milliequivalents** (meq), that a material can adsorb per unit weight or volume—the larger the number, the greater the nutrient-holding ability. The primary cations involved in plant nutrition are calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), and ammonium (NH_4^{+}), listed in order of decreasing retention on the CEC sites (Bunt 1988). Many micronutrient ions are also adsorbed, including iron (Fe^{2+} and Fe^{3+}), manganese (Mn^{2+}), zinc (Zn^{2+}), and copper (Cu^{2+}). These nutrients are stored on CEC sites on growing medium particles until they are taken up by the root system (fig. 2.2.2).

CEC has traditionally been measured on a weight basis for field soils, but CEC per volume is more meaningful for soil-less growing media, because of the relatively low bulk density of most media and the small volumes of the containers. Realistically, plants grow in a volume rather than a weight of growing medium, and volume is now the generally accepted basis for measuring CEC for horticultural purposes (Bunt 1988). CEC values for some typical growing medium components are compared in table 2.2.1. Vermiculite and peat moss have the highest CEC values, whereas inorganic materials such as perlite and sand have very low CEC values. In a list of CEC values for some of the standard growing media (table 2.2.2) (Bunt 1988), the peat–vermiculite medium has the highest CEC by a considerable margin.

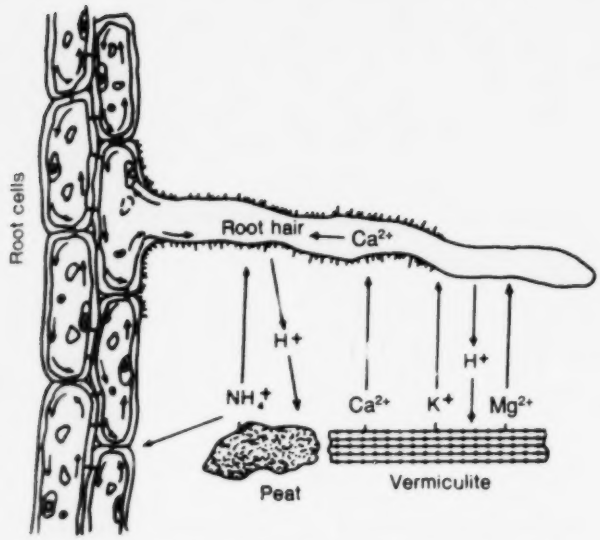


Figure 2.2.2—*The cation exchange capacity of growing media particles provides a fertility reserve that supplies mineral nutrients to the seedling root system between fertilizer applications (adapted from Davidson and Mecklenberg 1981).*

Table 2.2.2—*Cation exchange capacities for some standard growing media*

Growing medium composition	Cation exchange capacity	
	Weight (meq/100 g)	Volume (meq/100 cm^3)
Peat moss–vermiculite (1:1)	141	32
Peat moss–sand (1:1)	8	5
Peat moss–perlite (1:3)	11	1
Pine bark–perlite (2:1)	24	5

Source: adapted from Bunt (1988).

High CEC values are desirable for growing media because they maintain a fertility reserve that supports plant growth between fertilizer applications. The CEC can also hold cations in the growing medium against leaching, which can be very significant with the high irrigation rates used in most container tree nurseries. Certain growing medium components are better at resisting leaching than others, and generally speaking, the higher the CEC value for a medium, the greater its resistance to leaching. Comparing the amount of mineral nutrients recovered from two different types of growing media in the same volume of leaching water shows that the peat–vermiculite medium retained more nutrient cations than the peat–sand medium (fig. 2.2.3). Interestingly, the nitrate form of nitrogen (NO_3^-) was heavily leached from both types of growing medium because it is a negatively charged anion, which are repelled by the negatively charged cation exchange sites. Some materials have the ability to retain a small amount of anions—an **anion exchange capacity.** Whether this applies to nutrient ions like phosphate (PO_4^{3-}) is unclear however. Black (1988) reports that considerably more soluble P was leached from a 1:1 peat-vermiculite medium than from a mineral soil. Bunt (1988), although stating that PO_4^{3-} is leached from most types of growing media, showed that vermiculite apparently has a limited ability to absorb PO_4^{3-} ions (fig. 2.2.3).

A growing medium with a high CEC has another desirable property that is of interest to the container nursery manager. Because it is able to selectively adsorb and release cations from the growing medium solution, such a growing medium can buffer the seedling root system against sudden changes in pH or salinity (Whitcomb 1988).

Low inherent fertility. It may seem incongruous at first, but an initially low fertility level is actually a desirable attribute for growing media used in container nurseries (Mastalerz 1977, James 1987). Maintaining high levels of mineral nutrients, especially nitrogen, during seedling germination and emergence is unwise because of the possibility of encouraging damping-off fungi. In addition, many species of tree seedlings do not require any fertilization for the first few weeks of growth (except perhaps for phosphorus, which is best supplied through a nutrient injection system). Carlson (1983) reported that newly germinated seedlings took up few mineral nutrients until 2 weeks after germination, and Barnett and Brissette (1986) stated that the seed megagametophyte (endosperm) provides ample supplies of phosphorus and other essential mineral nutrients for early germinant growth.

The most important benefit of low initial fertility is that nursery managers can completely control mineral nutrient concentrations in the growing medium solution through fertilization. Inherently fertile growing media or media amended with incorporated fertilizers make it impossible to completely control seedling nutrition during the growing season. Growing media that contain slow-release fertilizers should not be stored for more than a few days because fertilizer salts can build-up and

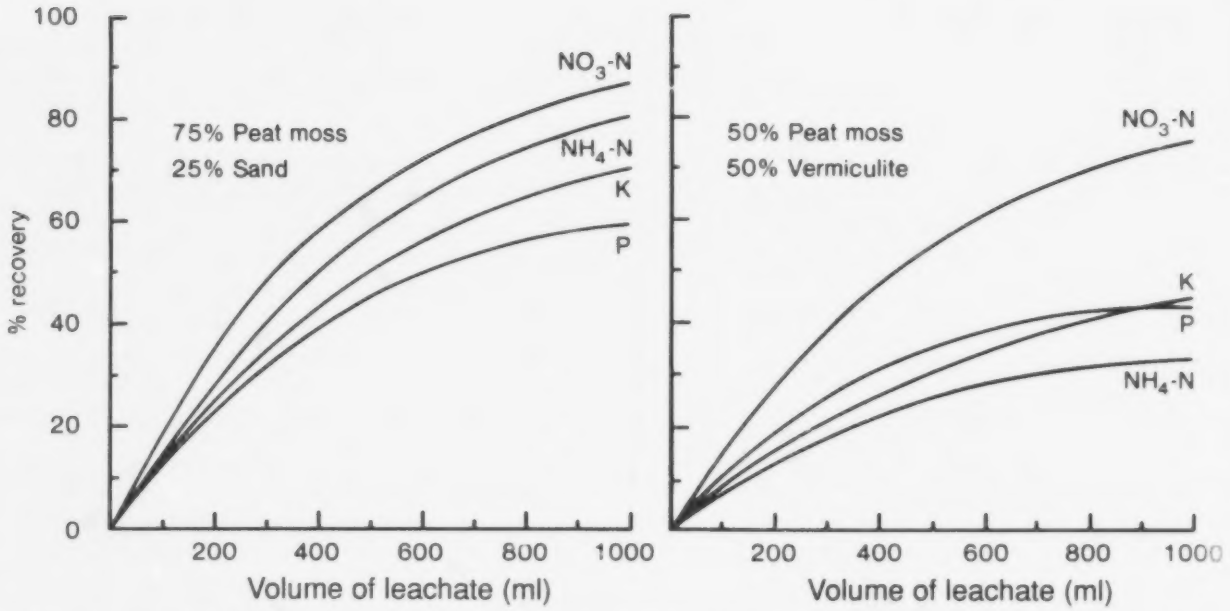


Figure 2.2.3—*The substitution of vermiculite* **(right)** *for sand in a peat moss–sand growing medium* **(left)** *greatly increases the cation exchange capacity and therefore reduces the amount of mineral nutrients lost to leaching; that is, it decreases the percentage of nutrients recovered in the leachate (adapted from Bunt 1988).*

possibly harm germinating seedlings (Handreck and Black 1984). Most container tree nurseries in North America are equipped with liquid fertilizer injection systems that allow custom fertilization at any time. Even though many brands of commercial growing media contain a starter dose of fertilizer, this practice cannot be recommended. A low initial fertility allows the container nursery manager to custom-fertilize at any time during the rotation and control seedling growth and phenology. The ability to completely leach all nutrients out of the growing medium and change nutrient ratios before the hardening period is often used to initiate bud set and cold hardiness (see chapter 1, volume four of this manual).

Most of the components of growing media used in container tree nurseries are inherently infertile (table 2.2.1), but there are some exceptions. Mastalerz (1977) reported that vermiculite contains "large amounts" of potassium and magnesium that are available for plant growth, although tests of peat–vermiculite media revealed only small amounts of these nutrients (table 2.2.3). Peat moss contains between 1 to 2.5% nitrogen,

Table 2.2.3—*Mineral nutrient analysis in a standard peat–vermiculite (2:1) growing medium*

Nutrient	Symbol	Units	Value
Mineral levels			
Ammonium nitrogen	NH_4–N	ppm	1.56
Nitrate nitrogen	NO_3–N	ppm	0.00
Phosphorus	P	ppm	1.30
Potassium	K	ppm	5.19
Calcium	Ca	ppm	1.83
Magnesium	Mg	ppm	1.19
Iron	Fe	ppm	0.143
Manganese	Mn	ppm	0.046
Copper	Cu	ppm	0.000
Zinc	Zn	ppm	0.002
Boron	B	ppm	0.031
Molybdenum	Mo	ppm	0.010
Other nutrient indices			
pH	—	—	4.06
Electrical conductivity	EC	µS/cm	1.00

Source: Scarratt (1986).

which is in an organic form and therefore not immediately available for plant uptake (Bunt 1988). The grade of peat moss is important, however, because the more decomposed forms, such as peat humus, may contain enough nitrogen to be a problem to seedling culture (see section 2.2.4.2).

Scarratt (1986) analyzed a standard peat–vermiculite growing medium for a variety of mineral nutrients and other chemical properties and found very low levels of all nutrients. Most micronutrients were present in very low concentrations, and copper (Cu) was completely absent (table 2.2.3). Commercial brands of growing media vary in their initial fertility levels, because many media contain supplemental amounts of fertilizer. Sanderson (1983) reviewed the fertility of 23 different brands and found that nitrate levels ranged from 3 to 154 ppm, phosphorus from 1 to 112 ppm, potassium from 8 to 244 ppm, and calcium from 100 to 3,160 ppm. Handreck and Black (1984) noted that growing medium components can contain varying levels of fertility, making it difficult to achieve uniformity between batches. These data indicate that growers should be aware of the fertility levels of their growing media and should routinely analyze growing media nutrient levels (see chapter 1, volume four of this manual).

Certain components of growing media can have a negative effect on fertility, however, and compete with the seedling for nutrients. Uncomposted organic materials, such as sawdust or bark, can tie-up a significant amount of nitrogen because the microorganisms that decompose these organics require high levels of this nutrient. Some types of pine bark can remove iron from the growing medium solution, and vermiculite can tie-up both iron and phosphorus (Handreck and Black 1984).

Proper balance of pore sizes. There is probably no other physical property of growing media that has been so thoroughly discussed and investigated as porosity. This attention is well deserved, however, because the relative pore space of a growing medium affects every aspect of seedling growth in containers. A properly balanced pore structure means good gas exchange for the root system, which directly affects all root functions such as water and mineral nutrient uptake. Milks and others (1989) state that plants growing in small containers often have growth problems due to poor aeration or low water-holding capacity of the growing medium. Aeration porosity is considered to be the most important physical property of any growing medium (Johnson 1968, Bragg and Chambers 1983).

A growing medium is composed of solid particles and the pore spaces that exist between them; these pore spaces are as important horticulturally as the particles themselves. The amount of pore space is expressed in terms of percent porosity and is a function of the size, shape, and spatial arrangement of the individual growing medium particles in the container (fig. 2.2.4).

Porosity can be functionally divided into three parts—total porosity, aeration porosity, and water-holding porosity (Bethke 1986, Handreck and Black 1984):

Total porosity. Total porosity is the measure of the total pore space of a growing medium, expressed as the percentage of its volume that is not filled with solid particles. For example: 1,000 ml of growing medium with a total porosity of 40% has 400 ml of pores and 600 ml of solid particles (fig. 2.2.4).

Aeration porosity. Aeration porosity is the measure of that part of the total pore space that is filled with air after the growing medium is saturated with water and then allowed to drain freely. The pores that contain air are relatively large and are termed **macropores** (fig. 2.2.5).

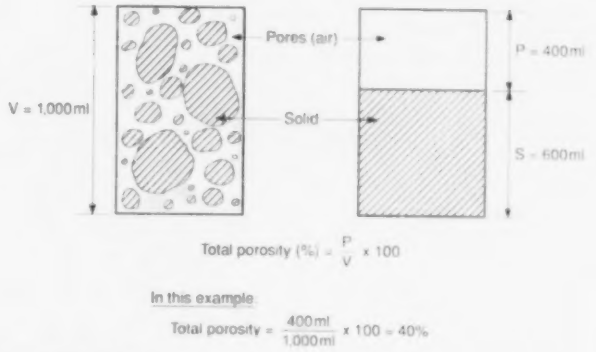


Figure 2.2.4—*A given volume of ovendry growing medium is composed of solid particles and the spaces (pores) that surround them. The total porosity is the proportion of the total volume of the growing medium that is not solid matter (adapted from Handreck and Black 1984).*

Water-holding porosity. Water-holding porosity is the measure of that part of the total pore space that remains filled with water after the growing medium is saturated with water and allowed to drain freely. The pores that contain water are relatively small and are termed **micropores** (fig. 2.2.5).

The porosity characteristics of a growing medium (the relative proportion between aeration porosity and water-holding porosity) depend on the types and sizes of the growing medium components. Bugbee and Frink (1986) varied the size of peat moss and vermiculite particles to produce growing media with aeration porosities from 1.0 to 33.6% by volume. Total porosity remained constant with the increase in aeration porosity, but water-holding porosity decreased linearly.

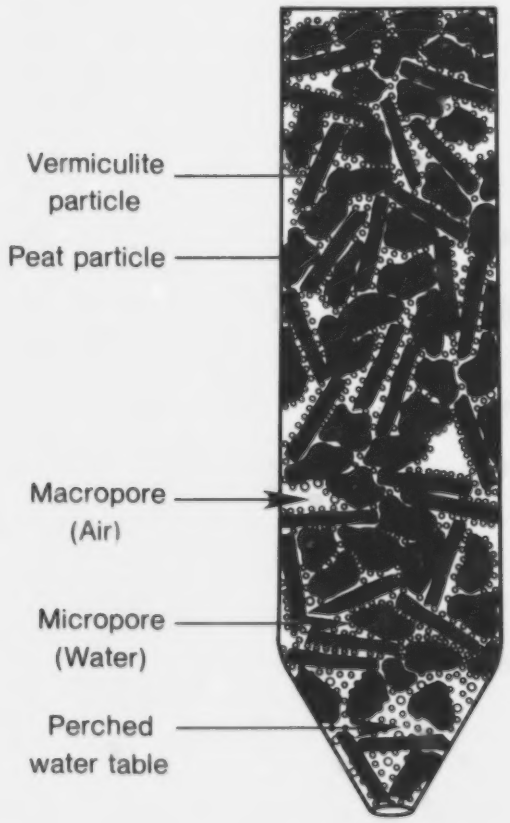


Figure 2.2.5—*The total porosity of a growing medium consists of relatively large macropores, which together constitute the aeration porosity, and relatively small micropores, which constitute the water-holding porosity. All containers also produce a perched water table, which creates a zone of saturated growing medium at the bottom of the container.*

Porosity can be measured in several different ways—aeration porosity can be measured by either volumetric or gravimetric means (Bragg and Chambers 1988). A relatively simple procedure for estimating total porosity, aeration porosity, and water-holding porosity is described in table 2.2.4.

Recommendations for the total amount and type of pore space for container growing media vary considerably. Handreck and Black (1984) reported that well-formulated growing media contain about 60 to 80% total porosity. Havis and Hamilton (1976) stated that the total porosity of a growing medium should exceed 50%, and that the aeration porosity should be 20 to 25%; Whitcomb (1988) recommended a higher aeration porosity of approximately 25 to 35% for container tree seedlings. Puustiarvi and Robertson (1975) recommended an even higher aeration porosity value of 45 to 50% because of the high oxygen demand of roots in greenhouse environments. This wide variation in porosity recommendations also reflects the physical characteristics of the different types of growing media and different ways in which porosity can be measured. A well-formulated growing medium will contain a mixture of macropores, for aeration and drainage, and micropores, for water-holding ability (fig. 2.2.5). The ratio of macropores to micropores varies considerably between different growing medium mixtures, however, and the porosity characteristics of a given medium cannot be predicted from the porosity of its individual components. Beardsell and others (1979) found that, although total porosity can be predicted from bulk density for certain growing media, the aeration and water-holding porosity cannot.

Factors affecting porosity. The porosity of a growing medium will vary with the characteristics of its components, the degree of medium compaction within the container, and the container height. In fact, container height is actually the principal factor controlling aeration porosity of growing media in a container (Milks and others 1989). There are four factors that affect porosity characteristics in containers: individual particle size, particle characteristics, particle size mixture, and changes in porosity over time.

Individual particle size. In bareroot seedling nurseries, soil structure is one of the most important properties

Table 2.2.4—*Determining the porosity characteristics of growing media: total porosity, aeration porosity, and water-holding porosity*

Equipment

1. Container with a drainage hole at the bottom.
2. Plug or waterproof tape for sealing the drainage hole.
3. Graduated cylinder or some other way of measuring liquid volume.
4. Watertight pan wider than the bottom of the container.

Procedure

1. Seal the drainage hole in the container and fill it with water. Measure the volume of water in the container and record as "container volume."
2. Empty and dry the container and fill it with growing medium. Slowly saturate the growing medium by gradually pouring water onto the surface. Continue adding water over a period of several hours until the growing medium is completely saturated (the surface glistens). Record the total volume of water added as "total pore volume."
3. Place the container over the watertight pan and remove the seal from the container drain holes. Allow all the free water to drain out of the container (this may take several hours). Measure the amount of this drainage water and record as "aeration pore volume."
4. Compute the total porosity, aeration porosity, and water-holding porosity as follows:

$$\textit{Total porosity}\ (\%) = \frac{\text{total pore volume}}{\text{container volume}} \times 100\%$$

$$\textit{Aeration porosity}\ (\%) = \frac{\text{aeration pore volume}}{\text{container volume}} \times 100\%$$

$$\textit{Water-holding porosity}\ (\%) = \text{total porosity} - \text{aeration porosity}$$

Standard

The aeration porosity should be approximately 25 to 35% for forest tree seedlings.

Source: adapted from Gessert 1976 and Whitcomb 1988.

affecting soil porosity but, in container nurseries, porosity is determined mainly by the range of particle sizes present in the growing medium (Handreck and Black 1984). Large particles do not pack together as closely as small particles and therefore produce greater total porosity. Aeration porosity and water-holding porosity have a complementary relationship: as the size of the particle increases, the water-holding porosity decreases and the aeration porosity increases (fig. 2.2.6).

The particle size that generates the proper mix of porosity apparently varies with the type of material. For peat moss, a particle size between 0.8 mm (0.03 inch) and 6.0 mm (0.24 inch) is recommended. If the peat particles are smaller than about 0.8 mm (A in fig. 2.2.6), micropores predominate, and the growing medium can easily become waterlogged. As the particle size increases, the ratio of macropores to micropores increases until, above about 6.0 mm (B in fig. 2.2.6), macropores predominate and the growing medium will not retain enough water for plant growth (Puustjarvi and Robertson 1975). The ideal particle size range for pine bark, on the other hand, is somewhat smaller. Handreck and Black (1984) reported that particles smaller than 0.5 mm (0.02 inch) had the most significant effect on the aeration and

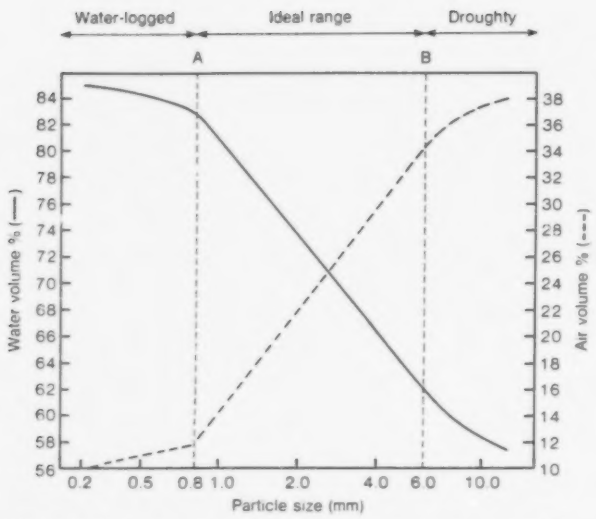


Figure 2.2.6—*Porosity in a growing medium is partially a function of particle size. As the particle size increases, the relative proportion of micropores decreases and the proportion of macropores increases and vice versa. This conceptual diagram was developed for a pure peat moss growing medium by Puustjarvi and Robertson (1975); the concept would be the same, although the numerical values would be different, for other growing media components.*

water-holding characteristics of the growing medium. They found that aeration porosity was decreased most by bark particles smaller than 0.25 mm (0.01 inch), whereas available water was increased more by particles in the range 0.10 to 0.25 mm (0.004 to 0.010 inch). The ideal size for sand is: 60% of the particles between 0.25 and 1.00 mm (0.01 and 0.04 inches), with no more than 3% smaller than 0.1 mm (0.004 inch) or larger than 2 mm (0.08 inch) (Swanson 1989).

Particle characteristics. The physical and chemical properties of the particles themselves also affect the porosity of a growing medium. Some components, such as peat moss and vermiculite, can be compressed, whereas others, such as perlite and bark, retain their original size under compression. Peat moss and especially vermiculite are fragile and can be easily broken into smaller particles during mixing and handling. Adding moisture to peat–vermiculite media during mixing can actually maintain the integrity of the particles (Milks and other 1989). The irregular surface texture of perlite particles generates macropore space (Moore 1988). Some organic components, especially uncomposted sawdust and bark, shrink during decomposition.

The particles of many growing medium components are not solid but contain internal spaces; this **internal porosity** is important to the horticultural properties of a growing medium. Some dense materials, such as sand particles, have essentially no internal pore space, whereas other materials, such as peat moss, vermiculite, and pine bark, have a substantial amount of internal porosity. The internal pore space of pine bark particles was determined to be about 43% of its total volume (Pokorny 1987). In addition to affecting the bulk density, this internal porosity may influence the moisture-holding and nutrient-holding properties of a growing medium. Although internally held water is considered by some researchers to be unavailable to plants (Spomer 1975), Pokorny (1987) demonstrated that seedling water uptake is increased by root penetration of pine bark particles. The spongy structure of sphagnum peat moss and vermiculite particles reflect high internal porosity, which is one reason for their popularity as growing medium components in container tree nurseries. Other porous materials, such as perlite, have sealed pores and therefore cannot absorb moisture. For example, perlite particles hold consistently less moisture and therefore provide more aeration than pumice particles of the same size (Johnson 1968). Because of these desirable properties, perlite is often added to a growing medium to increase the aeration porosity.

A comparison of the porosity characteristics for some common growing medium components (table 2.2.5) further illustrates the variation between different materials. Peat moss has the highest total and water-holding porosity because it has high internal pore space; fir bark has the lowest water-holding porosity because it is suberized and therefore water repellent.

Particle size mixture. Because growing media are usually a mixture of two or more components with a variety of particle sizes, the arrangement of the individual particles and their relationship to each other affects porosity. Whenever particles of different sizes are mixed together, the resultant volume is always less than the sum of the original volumes because the smaller particles fill in the pores between the larger ones. This is especially significant with angular particles such as some types of sand in which the pyramid-shaped particles are able to pack tightly together.

Table 2.2.5—*Comparison of dry and wet bulk densities and porosities for standard growing media components*

Component	Bulk density (kg/m^3)		Porosity relationships (% by vol)		
	Dry	Wet	Water-holding	Aeration	Total
Sphagnum peat moss	104.1	693.7	58.8	25.4	84.2
Hypnum peat moss	185.8	310.8	59.3	12.4	71.7
Vermiculite	108.9	640.8	53.0	27.5	80.5
Perlite	96.1	394.1	47.3	29.8	77.1
Fir bark	184.2	333.2	15.0	54.7	69.7
Sand	1,497.9	1,842.3	33.7	2.5	36.2

Source: modified from Johnson (1968).

Changes in porosity over time. The porosity of a given growing medium also changes over time because of decomposition of medium particles, siltation from irrigation and gravity, and root ingrowth. Langerud (1986) concluded that a physically stable medium is needed that can maintain the critically important balance between aeration and water-holding ability. Beardsell and others (1979) found that fine particles of pumice settled to the bottom of the container where they filled in between the larger particles and caused drainage problems. Many growers fail to appreciate the amount of pore space that becomes filled with roots; in fact, tree seedlings are expected to produce enough roots to form a relatively firm root plug at the end of the growing season. As new roots are produced, they penetrate and then expand to fill up the larger air-filled pores of the growing medium, gradually reducing the aeration porosity. This problem is more serious for larger tree seedlings that are grown for more than one growing season. To counteract this effect, growers should use a coarse, well-aerated growing medium that, although requiring more irrigation when the seedlings are small, will provide adequate air exchange when the seedlings mature.

Freedom from pests. One of the most serious problems with soil-based growing media is that native soil can contain a variety of pests, such as pathogenic fungi, insects, and nematodes, and weed seeds. Because of these pests, soils need to be pasteurized with heat or sterilized with chemicals before they are used in growing media. With the advent of artificial growing media, the use of pasteurization has decreased substantially because most of the commonly used components are considered to be pest-free (James 1987). Vermiculite and perlite are rendered completely sterile during manufacturing, when they are exposed to temperatures as high as 1,000 °C (1,832 °F). The pest-free status of peat moss is subject to debate (table 2.2.1). Bluhm (1978) reports that, although some peat moss products are advertised as "sterile" or "pest-free," peats have been shown to contain pathogenic fungi, weed seeds, and nematodes. Baker (1985) stated that water molds and other root-rotting fungi have been found in commercial peat moss from several geographic areas, including Canada. Bunt (1988) concluded that peat is not technically sterile, but because the microorganisms that it contains are not usually pathogenic, it is not usually sterilized before use (see chapter 1, volume five of this manual).

Some recent studies have found that some types of sphagnum peat moss actually inhibit certain pathogenic fungi, such as *Pythium* spp. Wolfinbechel (1988) inoculated *Pythium* into samples of sphagnum peat moss from five different locations and found considerable variability in their receptivity to the pathogen. Because it could be destroyed by heat pasteurization or fungicide treatment, this ability to suppress *Pythium* was attributed to the presence of beneficial microorganisms. Growing media formulated with this disease-suppressive peat moss could inhibit the development of *Pythium*-related damping-off and root rot. One commercial supplier, Ball Seed Company, has already released a peat-based growing medium that is "naturally suppressive" to *Pythium* diseases.

2.2.3.2 Characteristics that affect nursery operations

In addition to container characteristics that influence seedling growth, nursery managers must consider growing media properties that relate to the operational aspects of container tree nursery management. Factors such as cost and availability, uniformity and reproducibility, bulk density, dimensional stability, durability and ease of storage, ease of mixing and loading, rewettability, and the ability to produce a firm root plug are also important in the selection of a growing medium or individual components.

Reasonable cost and availability. Cost is one of the most significant, yet often overrated, factors in selecting growing media or their components. Because growing media have such an overriding effect on container seedling growth, nursery managers should not make cost

the determining factor when selecting a medium. Swanson (1989) stated the case well—price should not be the first priority in choosing a commercial growing medium or medium components, unless it is essentially prohibitive.

Availability has an effect on other operational aspects of a growing medium, especially uniformity and cost (Swanson 1989). Most of the materials used to formulate growing media are inexpensive in themselves but are bulky and sometimes heavy and therefore expensive to ship. Primarily because of shipping costs, a material that is inexpensive in one location may be prohibitively expensive in another. Many components are produced in restricted geographic areas and are either difficult to obtain or prohibitively expensive in other areas. Sphagnum peat moss is easily accessible and relatively cheap in Canada and the northern United States but is considered uneconomical in many parts of the world. Sand, on the other hand, is a growing medium component that is found worldwide at a relatively low cost. Prices of media components also may change: materials that are initially inexpensive, such as pine bark, may become costly due to high demand and competition with other uses (Whitcomb 1988).

High degree of uniformity and reproducibility. Both the components and the resultant growing media must be uniform in quality and reproducible from batch to batch. Some materials, such as peat moss and sand, can vary considerably between locations. Although **peat moss** is used as a generic term, the quality of this popular growing medium component varies with respect to the type of plant that composes the peat and the climate under which the peat was deposited. Mastalerz (1977) recommends standardization of growing media and medium components to ensure that each batch has the same physical, chemical, and biological properties. A growing medium that varies in physical or chemical characteristics can cause serious problems with irrigation, fertilization, and other cultural practices (see section 2.2.5.1). A good growing medium must also be reproducible in order to guarantee crop uniformity and maintain crop production schedules (Whitcomb 1988). The ability to consistently reproduce a uniform growing medium from crop to crop is one of the most important cultural factors in successful container tree nursery management.

Low bulk density. The bulk density of a growing medium is defined as weight per unit volume and is usually expressed in grams per cubic centimeter (g/cm^3) or kilograms per cubic meter (kg/m^3); the English units are pounds per cubic foot. The bulk density of a specific growing medium is a function of three factors:

- The bulk densities of the particles composing the medium.
- The compressibility of the particles.
- The arrangement of these particles with respect to one another.

Bulk densities of different growing medium particles vary considerably depending on their chemical composition and physical structure. Although Handreck and Black (1984) estimated the bulk density of average mineral particles at approximately 2.6 g/cm^3 (162.3 pounds per cubic foot) and average organic matter particles at 1.55 g/cm^3 (96.8 pounds per cubic foot), such averages are of limited usefulness because the compressibility and arrangement of the particles also affect bulk density values. Mineral particles can vary from solid sand to highly porous vermiculite, and organic particles from rigid bark to spongy peat moss.

The bulk density of a growing medium in a filled container is also a function of the internal arrangement of the individual particles. Although Beardsell and others (1979) found that total porosity could be predicted from bulk density for some types of growing media, aeration and water-holding porosity are often related to how densely the medium is compacted during the filling process (compaction is discussed in detail in section 2.2.7).

Bulk density is traditionally measured on an ovendry weight basis, but wet bulk density is also important for operational reasons. Some materials, such as peat moss and vermiculite, are able to absorb many times their own weight in water. Nelson (1978) reported that a growing medium consisting of vermiculite and perlite had a bulk density of around 0.51 g/cm^3 (32 pounds per cubic foot) when saturated, compared to a dry weight of only 0.10 g/cm^3 (6.5 pounds per cubic foot). Growers interested in keeping their media light in weight may want to consider perlite as a component because this material is relatively hydrophobic. A growing medium consisting of a mixture of peat moss and perlite would, therefore, have a saturated weight much lower than that of a peat moss–vermiculite mixture (Whitcomb 1988).

Both dry and wet bulk densities for common growing medium components are listed in table 2.2.5. Some materials, such as peat moss and vermiculite, have much higher wet bulk densities than dry bulk densities. Sand has obviously the highest values because of its higher particle density, and the small difference between the wet and dry values reflects a low water-holding capacity. In ornamental nurseries, the high bulk density of sand adds stability to single, free standing containers so that top-heavy plants do not blow over; this property is inconsequential for the small, aggregated containers used in most forest tree nurseries. Dry bulk density is operationally important for shipping and handling of dry medium components, but wet bulk density affects the handling and shipping of the container seedlings when the growing medium is saturated. Based on ease of handling, therefore, components with low bulk densities would have an advantage in container tree nurseries.

Dimensional stability. A growing medium should not shrink or swell excessively during use. Bilderback (1982) lists three different types of volume changes that can occur.

1. **Shrinkage due to expansion and contraction.** Materials such as peat moss can shrink during periods of alternating wetting and drying. Harlass (1984) reported that if some peat-based media are allowed to dry out excessively, they can pull away from the container wall, making uniform rewetting difficult.

2. **Decomposition of organic materials.** Organic components that were not properly composted will lose volume as they decompose (see following section on durability and ease of storage).

3. **Space–volume shrinkage.** Small particles can fill in the pore spaces between larger particles; the greater the difference in particle sizes, the greater the change in volume. Whitcomb (1988) discussed the poor aeration that resulted when fine vermiculite particles were carried to the bottom of the container with percolating irrigation water, filling the pore spaces and raising the level of the perched water table. Sand or pumice with a range of particle sizes is also not recommended because the smaller particles gravitate to the bottom of the container over time and reduce porosity.

Durability and ease of storage. Most of the popular components of growing media are durable and will not decompose or otherwise change over time. Uncomposted organic materials can decompose considerably during the cropping cycle and are therefore not recommended for growing media (Nelson 1978). Composted organic materials, including sawdust, wood chips, and bark, can be used, however. Pine bark does not change volume appreciably because of its slow decomposition rate, but even so most nursery managers prefer aged or composted bark (Bilderback 1982). Peat moss can vary considerably in its degree of decomposition, which can be rated on a 1 to 10 scale using the von Post system (Puustjarvi and Robertson 1975).

Initially sterile materials that are ordered in bulk quantities can be contaminated with weed seeds or other pest propagules during storage. For this reason, batches of premixed growing medium or medium components should be purchased in sealed plastic packages and stored out of direct sunlight, which will rapidly break down the plastic covering.

Ease of mixing and filling into containers. This factor is particularly important for nursery managers who custom mix their own batches of growing media. Uniform mixing can be difficult to achieve because of differences in the bulk density, particle size, and moisture content of the various components. Growing medium components should not aggregate or clump during storage and should flow easily during the mixing and filling operations. Peat moss and pine bark are shipped relatively dry but must be thoroughly wetted before mixing; this can be operationally difficult, however, because these organic materials are often hydrophobic at low moisture contents (see section 2.2.5.4 for more information on wetting agents). Flowability is especially important when filling the small-volume containers typically used in forest tree nurseries. These containers have correspondingly small top diameters that "bridge" easily and prevent the medium particles from flowing and uniformly filling the container.

Ease of rewetting. Some components, such as peat moss and bark, can become hydrophobic if allowed to dry out excessively, which can reduce irrigation infiltration rates. This problem is particularly serious during the dormancy induction period, when container managers withhold irrigation to induce seedling moisture stress. Bunt (1988) stated that the difficulty in rewetting peat is due to a film of air trapped on the surface of the peat particles and to the presence of iron humates, which repel water. Bark particles can also be difficult to rewet, and Pokorny (1979) stated that this hydrophobicity is

caused by both physical and chemical factors: most bark particles are covered with organic chemicals that resist water absorption and their rough surfaces create a surface tension that also physically repels water. Bilderback (1982) recommended using surfactants if the bark is below 35% moisture content. Surfactants, also called wetting agents, are routinely added during the mixing procedure to increase wettability of growing medium components (see section 2.2.5.4 for more information on surfactants).

Promotion of firm root plug formation. This operational characteristic is unique to forest tree nurseries because the shippable seedlings are removed from the container before planting. Container seedlings are expected to maintain a firm root plug during handling, shipping, and planting. A cohesive, resilient plug is especially important when the seedlings are planted with a dibble or other planting tool that makes a hole the same size and shape as the container. The growing medium and other cultural practices must be designed to promote adequate root growth throughout the container so that a firm root plug develops by the end of the growing season (fig. 2.2.7A). Growing media that do not pack evenly in the container or inhibit aeration can result in a poorly formed root system that does not extract easily from the container or does not maintain the integrity of the root plug during handling and shipping (fig. 2.2.7B). Lackey and Alm (1982) rated "styroplug quality" of conifer seedlings grown in 6 different types of growing media and found that two brands of commercial growing media produced plugs with the highest quality rating. Tinus (1974) evaluated the survival and growth of ponderosa pine seedlings with different "root plug integrity" ratings; both survival and growth decreased significantly as the root plug deteriorated (table 2.2.6).

Figure 2.2.7—*The root system of container tree seedlings should form a firm plug* **(A)** *when extracted from the container. A poorly formulated growing medium can create conditions unfavorable for root growth, and the resultant seedling root system will not form a plug* **(B)**.

B

Table 2.2.6—*Effect of root plug integrity on the outplanting survival and growth of ponderosa pine container seedlings*

Root plug integrity(%)	First-year survival (%)		First-year growth (cm)
	1972	1973	1972
100	95 a	92 a	4.2 a
75	90 ab	72 b	3.7 b
50	85 b	78 b	3.0 c
25	87 b	40 c	3.0 c
0	79 c	15 e	2.6 c

Values in columns with no letters in common differ significantly (p = 0.05).

Source: adapted from Tinus (1974).

2.2.4 Components Used in Formulating Growing Media for Tree Seedlings

Although pure peat is used in some northern container tree nurseries, most modern growing media consist of two or more different **components** that are selected to provide certain physical, chemical, or biological properties. Other **amendments**, such as fertilizer or wetting agents, are sometimes added during the mixing process. For purposes of clarity, a growing medium component usually constitutes a large percentage (>10%) of the mixture, whereas an amendment is defined as a supplemental material that contributes less than 10% to a medium (Gladon 1988) (amendments will be covered in section 2.2.6).

The Container Nursery Survey revealed that only 5 materials were used for growing media in forest tree nurseries in the United States and Canada: peat moss, sawdust, sand, vermiculite, and perlite.

A typical growing medium used in horticulture today is a composite of two or three components. Mixtures of organic and inorganic components are popular because these materials have opposite, yet complementary, physical and chemical properties. Beardsell and others (1979) found that some of the physical properties of growing medium mixtures, such as water-holding ability, can be predicted from the characteristics of the individual components.

2.2.4.1 Organic components

Function of the organic component. Organic materials are desirable components of growing media because they generate a large proportion of micropores, and thus produce a high water-holding capacity, yet are resilient enough to resist compaction. Organic matter also has a high CEC and can therefore retain nutrient ions against leaching and provide a buffer against rapid changes in salinity.

The amount of organic material used in growing media varies considerably, generally ranging from 25 to 50% (by volume), but sometimes up to 100% (Mastalerz 1977). Joiner and Conover (1965) found that the best proportion of organic material was from 40 to 50%, and Harlass (1984) reported that mixes containing more than 50% organic matter may actually have less pore space.

Although many different types of organic matter have been used for growing media in ornamental container crops (Mastalerz 1977, Bunt 1988), peat moss is the most commonly used organic material in forest tree nurseries. The only other organic material reported in the Container Nursery Survey was sawdust, which was mentioned by only two nurseries.

Peat moss. Although samples of peat moss may appear similar, they can have very different physical and chemical properties. Peats are formed when partially decomposed plants accumulate under water in areas with low temperatures and low oxygen and nutrient levels (Peck 1984). Peats can be composed of several species of plant including mosses, sedges, and grasses. The species of plant, its degree of decomposition, variation in local climate, and water quality all contribute to differences in peat moss quality and determine its value as a growing media component (Mastalerz 1977).

There are several different systems for classifying peat; for horticultural purposes, the principal plant species and the degree of decomposition are most important. The American Society for Testing Material (ASTM) uses a 5-class rating system based on the type of plant composing the peat and the organic fiber content (Bunt 1988, Mastalerz 1977, Hellum 1975). Analyzing the physical and chemical properties of peat moss is time consuming and technically demanding, and therefore nursery managers generally rely on the information provided by the suppliers. One newly developed analytical procedure, infrared spectroscopy, can determine the botanical composition, degree of humification, cation exchange capacity, nitrogen content, and other physical and chemical properties of a peat sample (Lehtovaara and others 1988). Some physical and chemical characteristics of the principal horticultural grades of peat moss are provided in table 2.2.7, and the four grades can be described as follows.

1. Sphagnum peat moss. This classification requires a minimum 90% organic matter on a dry weight basis, with over 75% of this material being mosses of the genus *Sphagnum*. There are approximately 335 species of sphagnum moss in the world (Puustjarvi 1975); Hellum (1975) reports that there are 25 species in Alberta alone and that *S. fuscum* is one of the most desirable. The stems and leaves of sphagnum peat moss are characteristic, and the fibrous, unicellular structure of the foliage can be diagnostic (fig. 2.2.8). The leaves of sphagnum moss contain a large number of pores that form an internal capillary system capable of storing large volumes of available water; in fact, Peck (1984) estimates that 93% of the water in this internal pore space is available to plants.

Table 2.2.7—*Characteristics of various types of horticultural peat moss*

Type of peat moss	Plant composition	Degree of decomposition	pH	Water-holding capacity (%)	Mineral nutrient content (% ash)	Mineral nutrient content (% N)	Dry bulk density (kg/m³)
Sphagnum peat	*Sphagnum* spp.	Very low	3.0–4.0	1,500–3,000	1.0–5.0	0.6–1.4	72.1–112.1
Hypnum peat	*Hypnum* spp. *Polytrichum* spp. *Sphagnum* spp.	Low	5.0–7.0	1,200–1,800	4.0–10.0	2.0–3.5	80.1–160.2
Reed-sedge peat	Reeds, sedges, grasses, & cattails	Medium	4.0–7.5	400–1,200	5.0–18.0	1.5–3.5	160.2–288.4
Peat humus	Not identifiable	High	5.0–7.5	150–500	10.0–50.0	2.0–3.5	320.4–640.8

Source: modified from Lucas and others (1965).

In addition to their physical characteristics, types of peat moss can be identified by their geographic origin. Sphagnum moss only grows in cool, northern climates. Hellum (1975) stated that desirable sphagnum bogs are found only in the boreal forest and that peat bogs in the southern part of Alberta contain a low proportion of sphagnum moss because of alkaline water and soil conditions. Most peat mosses produced in the United States contain a low proportion of sphagnum moss, with the exception of those from northern states such as Minnesota, Michigan, Maine, and Washington (Lucas and others 1965).

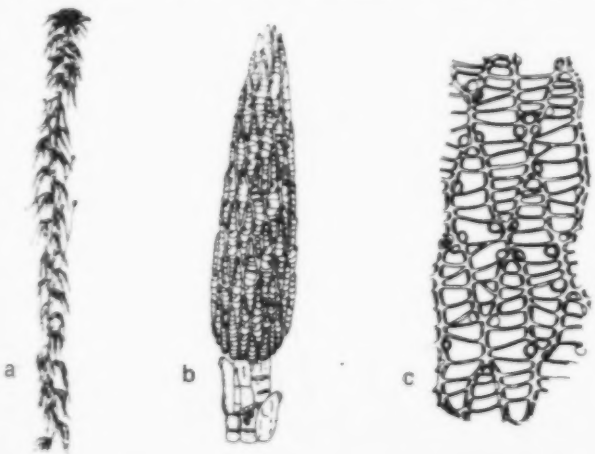


Figure 2.2.8—*Peat moss derived from sphagnum moss plants (for example,* Sphagnum cuspidatum*) can be identified by the characteristic open pore structure of the leaf cells (***a** *= whole plant,* **b** *= leaf,* **c** *= close-up of internal leaf structure) (modified from Peck 1984).*

There is considerable variation in peat moss quality, even in the type harvested from sphagnum bogs; Carlson (1983) stated that peat moss quality varied not only between different bogs, but even vertically within the same bog. Scagel and Davis (1988) evaluated the physical and chemical properties of peats used in British Columbia container tree nurseries and found highly variable results. A laboratory comparison of the physical properties of four commercial brands of sphagnum peat moss revealed significant differences in many of the properties (table 2.2.8). Carlson (1983) provided standards for physical property tests and recommended that such tests be performed on all potential peat sources.

Peck (1984) distinguished between two different types of sphagnum peat moss: **light peats** and **dark peats**. Light sphagnum peats are so-named because they are light in both color and weight; they have a high volume of internal pores, a large proportion (15 to 40%) of which is classified as aeration porosity. Dark sphagnum peats are twice as heavy as light peats and contain less total pore space, with correspondingly less aeration porosity. The CEC of dark peats is over twice that of light sphagnum peats. Peck (1984) considers dark peats less suitable for long-term container seedling culture because they are less durable and less resilient than the lighter colored peats.

Table 2.2.8—*Four different brands of sphagnum peat moss varied in physical properties affecting conifer seedling growth*

Physical characteristics*	Sphagnum peat moss brands			
	A	B	C	D
Saturated weight (g/l)	718.0	735.0	660.0	685.0
Dry weight after saturation (g/l)	58.0	94.0	64.0	73.0
Ash content (%)	4.3	9.0	8.0	9.1
Bulk density (g/ml)	0.054	0.088	0.060	0.068
Specific gravity (g/ml)	1.53	1.56	1.56	1.56
Total porosity (%)	96.0	94.0	96.0	96.0
Water capacity by volume (%)	62.0	60.0	56.0	57.0
Air capacity (%)	35.0	34.0	40.0	38.0
Coarse–fine ratio	0.35	0.17	0.34	1.60

* Procedures for determining these characteristics and acceptable standards are explained in detail in the source.
Source: Carlson (1983).

2. Hypnum peat moss. The organic matter content of this type of peat moss must exceed 90% of the ovendry weight, more than 50% of which must be composed of mosses of the *Hypnum* genus (Bunt 1988). Hypnum peat moss is generally less expensive than sphagnum moss but may contain weed seeds or plant pathogens because of the conditions under which it was formed (Whitcomb 1988). Mastalerz (1977) reported that much of the peat moss produced in the northern United States contained a high proportion of hypnum mosses. Hypnum mosses decompose more rapidly than sphagnum mosses but are used in the growing media for some horticultural crops, especially for acid-intolerant plants (Peck 1984). Growing media containing a high percentage of hypnum peat moss are not recommended for container tree seedlings.

3. Reed and sedge peat moss. These peats are formed from rushes, grasses, sedges, and similar marsh plants; an ovendry sample must contain a minimum 33% of these materials on a dry weight basis (Bunt 1988). Reed–sedge peat mosses are generally finer textured, more decomposed, and less acid than sphagnum peat moss. Mastalerz (1977) considers this peat moss class unsatisfactory for use in growing media because of its rapid rate of decomposition, fine particle size, and low fiber content.

4. Peat humus. Peat humus includes all types of peat moss that are in such an advanced stage of decomposition that the constituent plants are not recognizable. Peat humus is usually derived from reed–sedge or hypnum peat moss (Lucas and others 1965) and is composed of less than 33% total peat fiber (Bunt 1988). Because this grade of peat moss often contains a high proportion of foreign material such as silt and clay, it is considered undesirable for use in growing media (Mastalerz 1977).

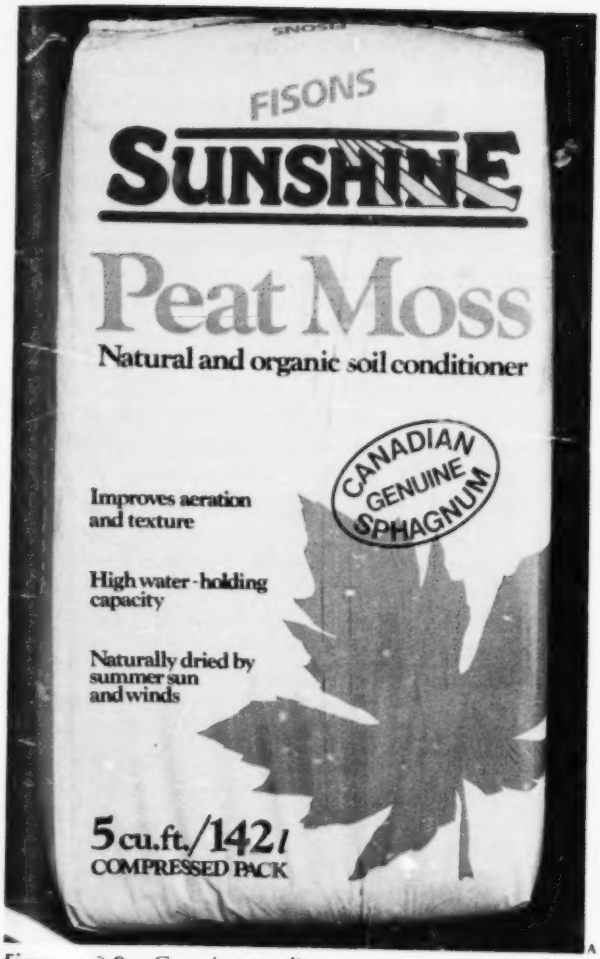
Although other grades of peat moss have some horticultural applications, sphagnum peat moss is the only type that can be recommended for production of container tree seedlings (fig. 2.2.9A). Operational trials comparing growing media containing sphagnum peat moss and media containing other peat moss types have produced startling growth differences (fig. 2.2.9B).

In addition to the type of plants, peat texture is determined by the manner in which the peat is harvested and processed. Peat can be harvested from bogs by several processes, including block cutting and hydraulic mining. Block cutting involves cutting slabs of peat from the bog and then shredding the peat to the proper texture, whereas hydraulic mining mechanically shreds the peat and then dredges the liquid slurry from the bog (Hellum 1975). The harvesting method can affect the physical characteristics of peat moss, especially the porosity (Wilson 1985). The hydraulic mining process breaks down the structure of the peat particles, causing it to pack more tightly with a resultant loss in total and aeration porosity (table 2.2.9). Block-cut peat is usually preferred for container growing media because of its coarser texture; the ASTM defines coarse peat as having particles larger than 2.38 mm (about 0.1 inch) (Bunt 1988).

Table 2.2.9—*Comparison of porosity characteristics of peat moss obtained by different harvesting techniques*

Characteristic*	Harvesting method	
	Block cut	Mined
Total porosity	95.4	91.8
Aeration porosity	46.0	32.5
Water-holding porosity	49.4	59.3
Readily available water	18.1	17.5

* Units for each characteristic are relative values obtained from particle size measurements.
Source: adapted from Wilson (1985).



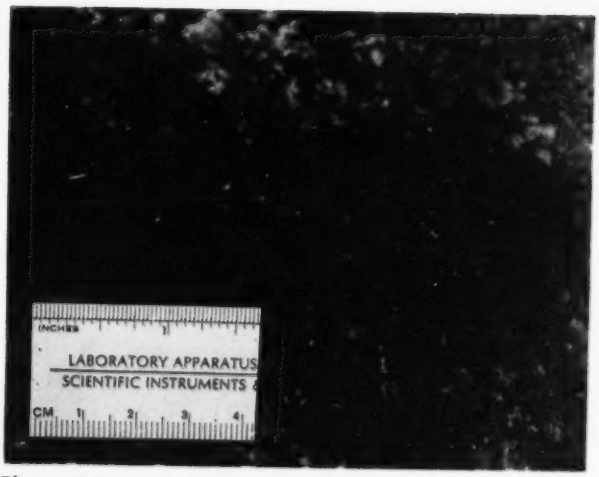


Figure 2.2.10—*Growers sometimes utilize innovative sources of organic matter as a substitute for peat moss in growing media. The bark of tree ferns has been used for the organic growing medium component in tropical climates, where peat moss is prohibitively expensive.*

Figure 2.2.9—*Growing media containing sphagnum peat moss (**A**, **left**) have consistently proven superior for the production of container tree seedlings, compared to media composed of lesser grades of peat moss (**B**, **right**).*

Composted sawdust, bark, and other organic materials. Although peat moss is the most common organic component used in growing media in container tree nurseries in the United States and Canada, other organic materials have potential, especially in warmer climates where the cost of sphagnum peat moss can be prohibitive (fig. 2.2.10). Wood residues, including sawdust, bark, and wood chips, are alternative organic materials that can be used for growing media, depending on local availability and cost. Sewage sludge and mushroom compost have also been tested in ornamental nursery

applications (for example, Chong and others 1988). Lippitt (1989) tested rice hulls as an organic component in a forest nursery and reported that they are cheap, readily available, consistent in quality, resistant to decomposition, and mix well. Bunt (1988) and Mastalerz (1977) discussed alternative organic components that have been used in growing media for ornamental nurseries.

Because of their high carbon to nitrogen ratio (C/N), wood residues must be composted with supplemental nitrogen amendments before use (table 2.2.10). Fresh bark can have a C/N ratio of 300:1 and so is frequently composted before use. Organic materials vary considerably in decomposition rates and in the amount of nitrogen required during composting, even within one genus of tree (table 2.2.11). An excellent overview of the biochemistry and methodology of composting is provided by Poincelot (1972), and composting is also discussed in detail in Mastalerz (1977), Bunt (1988), Whitcomb (1988), and Nelson (1978).

Sawdust. Sawdust is commonly used in horticultural growing media and is usually composted before use. Because of the inherent differences in chemical properties between different woods, however, the suitability of sawdust as an organic growing media component is extremely variable. Mastalerz (1977) stated that sawdust from incense-cedar, walnuts, or redwood is known to have direct phytotoxic effects, and Gates (1986) related that sawdust from western redcedar is toxic to many horticultural plants. Stewart (1986) reported that conifers grown on peaty soil types accumulate high levels of manganese, and that sawdust from such trees is phytotoxic if these materials are used for growing media. Worrall (1976) investigated the properties of sawdust from several species of *Eucalyptus* and found that, even within this one genus, the presence of chemical toxins varied between tree species (table 2.2.11). Only sawdust from sawmills should be considered for growing media because other wood residues may contain preservatives or other harmful chemicals. Sawdust from coastal sawmills can contain high levels of salts, which can also be harmful to seedling growth (Gates 1986). Obviously, sawdust should be chemically tested before it is used in growing media. Another potential problem is uniformity of particle size; particle size analysis of sawdust revealed a considerable amount of variability (Scagel and Davis 1988).

Table 2.2.10—*Nitrogen required for composting various organic materials before use in growing media*

Type of organic material	N (kg/m^3)
Sphagnum peat moss	0.04
Redwood bark	0.18
Incense-cedar sawdust	0.47
Redwood sawdust	0.54
Douglas-fir sawdust	0.44
Ponderosa pine sawdust	1.19
Pine bark	1.48
White fir bark	1.90

Source: Johnson (1968).

Table 2.2.11—*The suitability of sawdust as a growing medium component can vary, even with trees of the same genus*

Tree species	Relative concentration of toxins	Relative nitrogen tie-up
Eucalyptus pilularis	8.2	1.0
E. andrewsii	6.5	1.2
E. microcorys	6.1	1.1
E. radiata	4.5	1.2
E. saligna	1.3	1.4

Source: modified from Worrall (1976).

Bark. Tree bark is probably the most promising of alternative organic materials, and when prepared properly, both pine and hardwood bark have found wide acceptance as components of growing media in ornamental container nurseries (Bunt 1988, Mastalerz 1977, Bilderback 1982). Pokorny (1979) reviewed the horticultural properties of pine bark, and Stewart (1986) described the production of a commercially available pine bark product, marketed internationally as Cambark®. A similar bark-based product (Peatgro®) is being used to produce container seedlings in South Africa (Nelson 1989).

Pine bark is naturally acidic, has a low initial fertility, and also possesses many other beneficial properties (table 2.2.1). Bark is usually added to a growing medium to increase its air porosity; as the proportion of bark in bark–vermiculite media was increased, the percentage of air space was significantly increased (Lennox and Lumis 1987). Pokorny (1987) found that bark particles have 43% internal porosity, which contributes water for plant growth. Composted bark has a much higher CEC

than raw bark and also has been shown to suppress the activity of pathogenic fungi (Hoitink 1980). Compared to standard peat–vermiculite mixes, growing media containing pine bark had significantly less seedling mortality after inoculation with species of *Pythium* and *Fusarium* (Pawuk 1981). In other situations, bark can replace peat for reasons of economy or availability. Milbocker (1987) estimated the cost of pine bark at half the cost of sphagnum peat moss.

Bark is usually incorporated in a mixture with other components. Stewart (1986) recommends adding 25 to 50% pine bark to peat moss to form a well-structured growing medium. The size of the bark particles is important, and Whitcomb (1988) recommends running bark through a hammermill with a 2- to 2.5-cm (0.75- to 1.0-inch) screen to produce a desirable range of particle sizes. Handreck and Black (1984) recommended a mixture of pine bark sizes, including approximately one-quarter to one-third in the < 0.5 mm (0.02 inch) range.

One of the biggest drawbacks of bark is its variability. Nurseries have reported problems in obtaining regular supplies of bark of consistent quality (Lippitt 1989). Two other potential problems with the use of bark are nitrogen deficiency and the presence of organic or inorganic toxins (Bunt 1988). Composting bark with supplemental nitrogen fertilizer supplies the nitrogen that microorganisms require during decomposition. The possibility and degree of phytotoxicity depend on the age of the bark, the season of collection, the species of tree, and the geographical location. Phytotoxicity is apparently related to the monoterpene or manganese content of the bark. More information and treatments for phytotoxicity are provided by Bunt (1988).

Sewage sludge. Sewage sludge is another organic material that has been used as a growing medium component in horticultural nurseries. Sludge is an extremely variable material depending on the raw materials involved and the stage of processing. Chong and others (1988) grew two ornamental woody plants in both primary and secondary sludge from two different papermills. They reported that the mineral nutrient content of these sludge products was variable, especially for nitrogen, which caused irregular plant growth. Simpson (1985) tested a compost of sewage sludge and woodwaste for production of conifer seedlings but found that this medium was inferior to the standard peat–vermiculite growing medium.

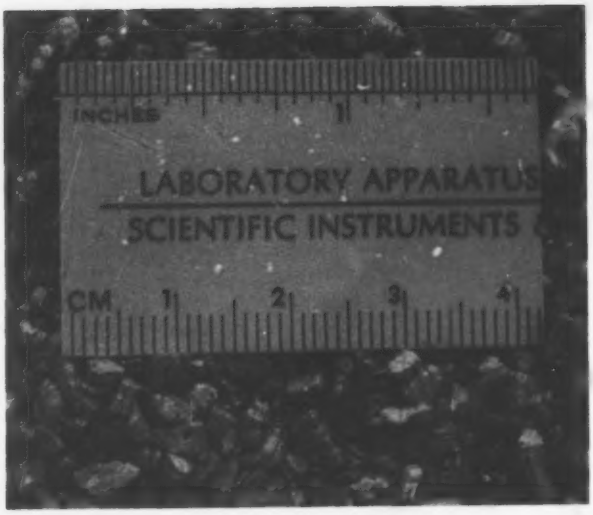
2.2.4.2 Inorganic components

Function of the inorganic component. Inorganic materials are added to growing media to produce and maintain a structural system of macropores that improves aeration and drainage and decreases water-holding ability (Mastalerz 1977). Many inorganic components have a very low CEC and provide a chemically inert base for the growing medium. Inorganic materials with high bulk densities, such as sand, are used to provide stability to large, free-standing containers in ornamental nurseries.

Three different materials are routinely being used as inorganic components in growing media in container tree nurseries in the United States and Canada: vermiculite, perlite, and sand. Based on the 1984 Container Nursery Survey, vermiculite was by far the most commonly used, perlite was second, and sand was mentioned by only one nursery.

Vermiculite. Vermiculite is an aluminum–iron–magnesium silicate mineral, mined in the United States and Africa, that consists of a series of thin, parallel plates. After the raw vermiculite mineral is mined, it is subjected to intense heat (up to 1,000 °C, or 1,832 °F), which expands the vermiculite particles to 15 or 20 times their original volume and gives them an accordian-like structure (Bunt 1988) (fig. 2.2.11).

Vermiculite has many unique properties that make it useful for horticultural purposes (table 2.2.1): it is lightweight and its plate-like structure generates a very high surface to volume ratio, producing a high water-holding capacity. The plates contain numerous cation binding sites, both externally and internally, which produce a high CEC; this property is unique for inorganic growing medium components, which are typically chemically inert. Bunt (1988) reported that, although vermiculite does not apparently have any anion exchange capacity, it can adsorb phosphate in available forms. Vermiculite contains some potassium and magnesium that are slowly released for plant uptake. Because of the high processing temperatures, vermiculite is completely sterile. The pH of vermiculite is variable, generally ranging around neutral (pH 7.0), too high for most conifer seedlings. This is not a problem, however, because vermiculite is normally mixed with a more acidic organic material such as sphagnum peat moss (Biamonte 1982, Mastalerz 1977).



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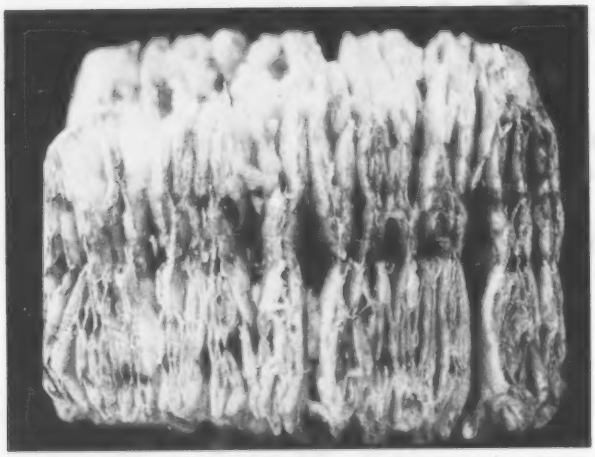


B

Figure 2.2.11—*Horticultural vermiculite particles (**A**) are accordion-like, because of their expanded structure of parallel plates (**B**), which creates an extensive internal surface area (**B**, courtesy of Biamonte 1982).*

Mastalerz (1977) recommended that only horticultural grades of vermiculite be used for growing media because insulation grades of vermiculite are often treated with water-repellent chemicals. The author, however, has used insulation grade vermiculite without any problems, and Goodwin (1975) also recommended its use in container tree seedling growing media. Tinus and McDonald (1979) stated that vermiculite sold for poultry litter or attic insulation is not only acceptable but cheaper. "Block fill" vermiculite has been treated with water repellents, however, and should not be used. Obviously, growers should test vermiculite or any other growing medium component before using it on a large scale.

Vermiculite is produced in four grades, based on particle size, which determines the relative proportion of aeration and water-holding porosity (table 2.2.12). Grades 2 and 3 are most commonly used in growing media; grade 2 is preferred when more aeration porosity is desired, whereas grade 3 produces more water-holding porosity. It should be emphasized that a vermiculite grade usually contains a range of particle sizes, depending on the size of sieves used by the manufacturer. Several nurseries in the northwestern United States have compared conifer seedling growth in growing media containing either grade 2 or 3 vermiculite and have found better growth with grade 2. Tinus and McDonald (1979) recommended grade 1 for containers of 164 cm^3 (10 cubic inches) or larger, and grade 2 for smaller containers. Vermiculite particles are structurally unstable in a moist medium and will compress over time (Ward and others 1987). For this reason, vermiculite should not be used alone or with sand but should be mixed with perlite or peat, which provide resistance to compaction (Bunt 1988).

Perlite. Perlite is an alumino-silicate mineral of volcanic origin that is mined in several countries, including the United States and New Zealand. After mining, the raw mineral is crushed and exposed to temperatures as high as 1,000 °C (1,832 °F), producing white, lightweight particles (fig. 2.2.12).

Perlite possesses many useful characteristics that make it desirable for growing media (table 2.2.1). One of these unique properties is its closed-cell structure; water adheres only to the surface of the perlite particles and therefore growing media containing perlite are well-drained and lightweight. Perlite is also rigid and does not compress easily, which promotes good porosity. Compared to other inorganic components, such as sand and grit, perlite increases the aeration porosity of peat-based growing media (Ward and others 1987). Because of the high temperatures at which it is processed, perlite is completely sterile. Perlite is essentially infertile—it contains almost no plant nutrients (table 2.2.13)—and has a minimal CEC (Bunt 1988, Moore 1988). The pH of perlite ranges around neutral (table 2.2.1), but this is not significant because it is usually mixed with acidic sphagnum peat moss (Nelson 1978).

Table 2.2.12—*Physical characteristics of various grades of vermiculite*

Grade	Bulk density (kg/m^3)	U.S. sieve size	Range of particle sizes (mm)	Aeration porosity (%)	Water retention (% weight)	Water retention (% volume)
1	64.1–112.1	3/8–16	1.2–10.0	44.3	297	30.7
2*	64.1–128.2	4–30	0.6–4.7	40.4	412	39.0
3*	80.1–144.2	8–100	0.1–2.4	29.9	530	52.4
4	96.1–176.2	16–100	0.1–1.2	24.5	499	54.4

* Standard horticultural grades.
Source: adapted from Biamonte (1982).

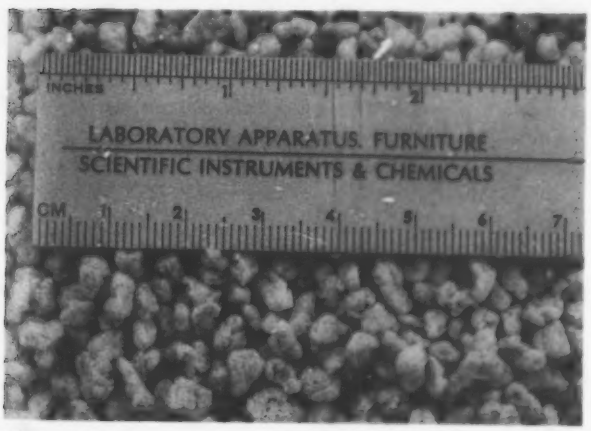


Figure 2.2.12—*Because of its closed-cell structure that repels water, perlite is often added to growing media to increase the aeration porosity and drainage.*

According to the Container Nursery Survey, perlite is a minor component of growing media in forest tree nurseries, usually constituting from 10 to 30% of the mix. Perlite is usually added to organic components, such as peat moss, to increase aeration porosity, which is particularly important in the smaller volume containers used in container tree nurseries. Perlite grades are not standardized, but grades 6, 8, or "propagation grade" are normally used in growing media (table 2.2.13). Perlite grades are also not uniform and contain a range of particle sizes, depending on the sieve sizes used during manufacturing.

Table 2.2.13—*Elemental composition and horticultural grades of perlite*

Element	Average composition (%)
Oxygen	47.5
Silicon	33.8
Aluminum	7.2
Potassium	3.5
Sodium	3.4
Iron	0.6
Calcium	0.6
Magnesium	0.2
Trace elements	0.2
Bound water	3.0
Total	100.0

Grade*	Average particle size (mm)	Commercial labeling
No. 6	3.35	Horticultural grade—coarse
No. 8	1.70	Horticultural grade—fine
Propagation	3.20	Propagation grade

* There are no standard perlite grades, so each manufacturer has its own rating system.
Source: Perlite Institute (1983).

Perlite has a couple of operational drawbacks. Horticultural grades of perlite can contain considerable amounts (4% by weight) of very fine particle sizes (Maronek and others 1986) that cause eye and lung irritation during mixing if the perlite is not premoistened. Because of its closed-cell structure, perlite has a tendency to float to

the top of the medium during irrigation (Mastalerz 1977); this is normally not a problem with the small proportions used in container tree seedling growing media. Gates (1986) reported that perlite particles tended to bind to the walls of Styrofoam block containers, which may damage root plugs when the seedlings are extracted.

Other inorganic materials. Other inorganic materials that have been used in growing media in horticultural nurseries include sand, pumice (fig. 2.2.13), scoria, cinders, calcined (heat-expanded) clays, rock wool, polystyrene flakes, and foam particles. The use of any of these materials will depend on cost and availability, but it is doubtful if any will supplant vermiculite and perlite as the primary inorganic components in North American container tree nurseries.

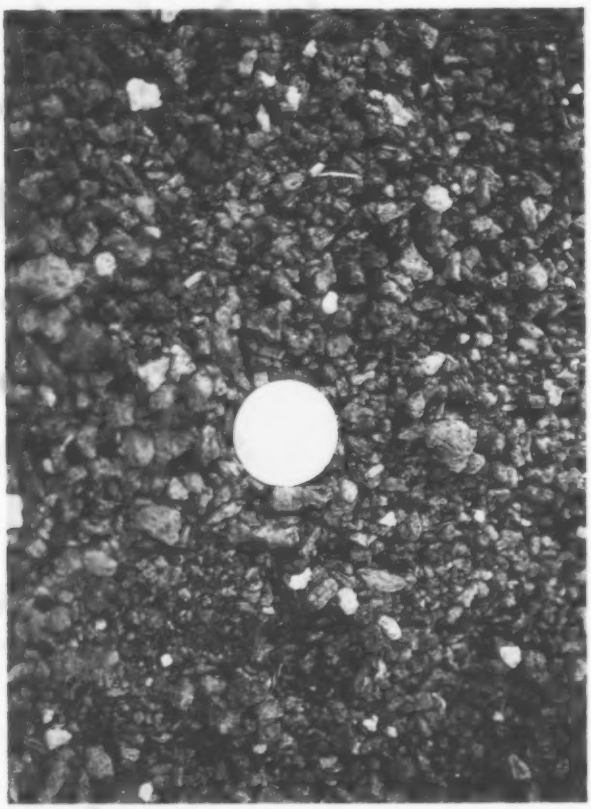


Figure 2.2.13—*Volcanic pumice is another native material that is being used as the inorganic component in growing media; it has physical properties similar to perlite.*

Sand was one of the most common materials used in many of the original horticultural growing media recipes. It is one of the most readily available materials that can be used for growing media and is relatively inexpensive. Size recommendations vary considerably: Whitcomb (1988) recommended a uniform particle size of 2 to 3 mm (0.06 to 0.12 inch), whereas Matkin and Chandler (1957) specified a fine sand with a diameter of 0.05 to 0.5 mm (0.002 to 0.02 inch). Swanson (1989) recommended that 60% of the sand particles be between 0.25 and 1.00 mm (0.01 to 0.04 inch), with less than 3% smaller than 0.1 mm (0.004 inch) or larger than 2 mm (0.08 inch). Although sands are often used to increase porosity, small sand particles can lodge in existing pore spaces and reduce aeration and drainage (Ward and others 1987). Sand does add stability to free-standing containers. Some sands are also contaminated with calcium carbonate, which can raise pH and cause nutrient availability problems (Bunt 1988). Although pH is not always a good indication of $CaCO_3$ content (Ward and others 1987), growers can test sands by adding a drop of dilute acid or even strong vinegar; a fizzing reaction indicates the presence of $CaCO_3$.

2.2.5.1 Interactions between growing media and cultural practices

Because of the diverse characteristics of the various growing media components, a container nursery manager can formulate a growing medium with almost any desired property. The physical, chemical, and biological properties of each growing medium are different, however, and are also affected by cultural practices used in the nursery, particularly irrigation, fertilization, and type of container. The timing of the growing season should also be considered. Scagel and Davis (1988) concluded that growers must adjust their cultural practices because of physical and chemical variability between different media. Carlson (1983) evaluated five different brands of Canadian sphagnum peat moss and found that each brand required slight modifications of cultural practices to produce optimum growth of spruce and pine seedlings.

Irrigation and fertilization practices. The water-holding and nutrient-supplying properties of a growing medium are a function of the different growing medium components and their interrelationships . Hoyle (1982) studied the effect of irrigation technique, type of fertilizer, and type of growing medium on the growth of yellow birch seedlings. Using two different peat moss–based growing media, he grew yellow birch seedlings under two irrigation systems and three fertilizer treatments. Seedling growth varied significantly between the two growing media, depending on which irrigation and fertilization treatment was applied (fig. 2.2.14). The container tree nursery manager must tailor irrigation and fertilization regimes to fit the characteristics of the growing medium and will have to alter these cultural practices if the medium is changed. Colombo and Smith (1988) grew two species of conifer seedlings in growing media containing peat moss from local or commercial sources over a range of different fertilization rates (fig. 2.2.15). Although the growth responses differed between the tree species, the largest seedlings were those grown in the commercial peat moss–vermiculite medium; the authors attributed this enhanced growth to better aeration and drainage. Irrigation practices had to be adjusted by the end of the growing season because of changes in the water-holding capacity of a peat–perlite growing medium (Langerud and Sandvik 1988). Scagel (1989) concluded that many growing media problems can be attributed to poor irrigation practices, rather than to the media.

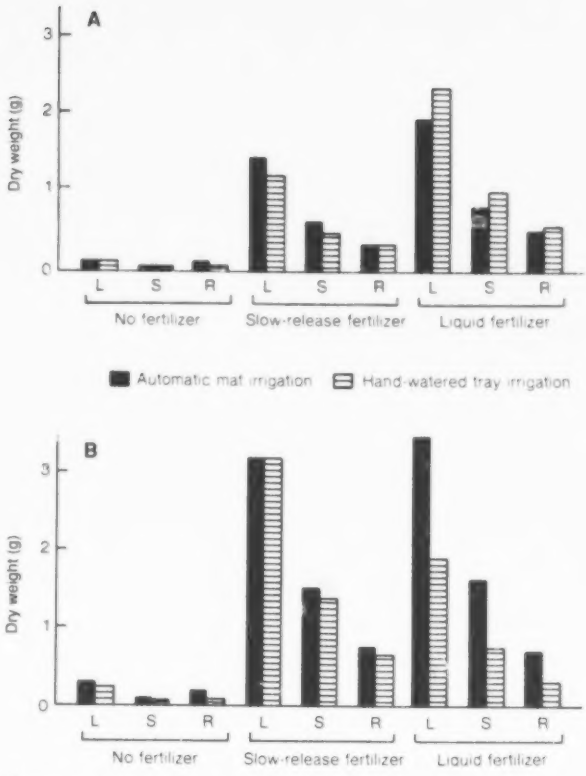


Figure 2.2.14—*The growth of yellow birch seedlings (L=leaves, S=stems, R=roots) was affected by the interrelationships of the growing medium, the type of irrigation system, and the type of fertilizer (adapted from Hoyle 1982).* ***A****, peat-perlite;* ***B****, peat-vermiculite.*

Type of container. Because of the perched water table that is inherent in container culture, the type of container will affect the performance of the growing medium. Short containers have a higher proportion of their volume in the saturated condition and will therefore require a growing medium with a greater aeration porosity than a taller container. Containers with porous sidewalls, like paperpots, have different water and nutrient relationships than impermeable containers and will therefore require a growing medium with more aeration porosity and a different irrigation regime than containers with solid walls. (See chapter 2, volume four of this manual for further discussion on water management in containers.)

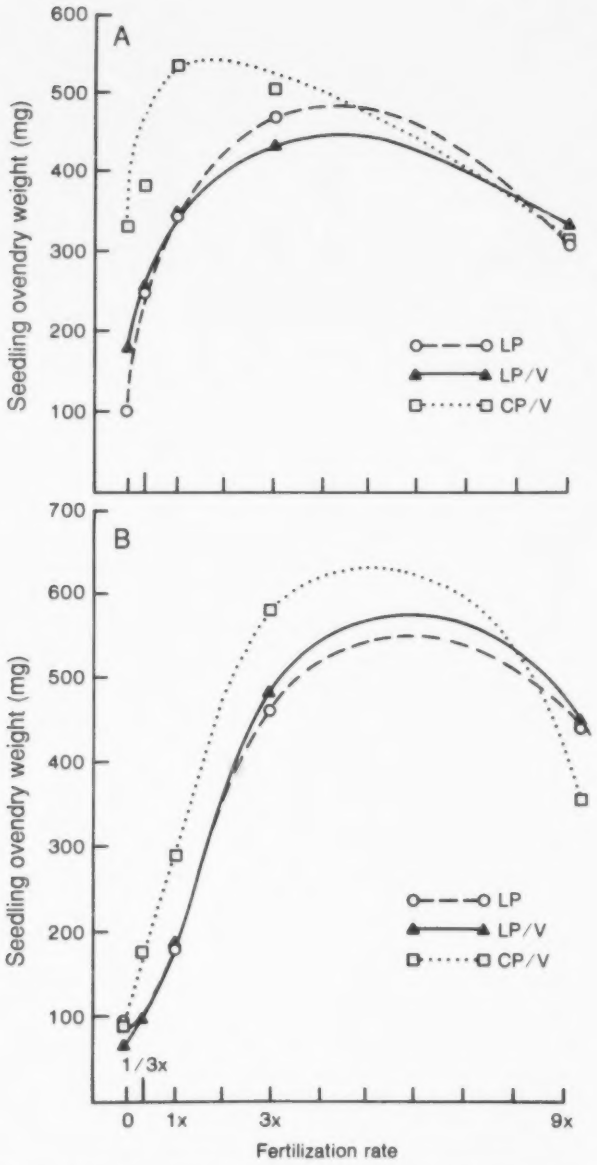


Figure 2.2.15—*Both black spruce* **(A)** *and jack pine* **(B)** *grew better in a commercial peat moss–vermiculite growing medium (CP/V) than in media composed of local peat moss (LP) or local peat moss and vermiculite (LP/V) when fertilized at one-third (1/3x), normal (x), and three times (3x) normal rates; the highest fertilization rate (9x) reduced growth in all media (adapted from Colombo and Smith 1988).*

Growing season. Many container tree nurseries produce more than one crop of tree seedlings per year and the type of growing medium may need to be formulated differently for different cropping cycles. Harlass (1984) reported that growing media with high water-holding capacities should not be used during the low light periods of fall or winter because the low evapotranspiration rates during these periods can lead to water-logged conditions. A more porous growing medium is best for fall and winter crops, whereas a growing medium with a higher water-holding capacity is better for spring and summer crops.

2.2.5.2 Practical considerations

Container tree nursery managers are faced with many different considerations when selecting a growing medium that will match their cultural regimes. The cultural and operational characteristics that were discussed in section 2.2.3 (table 2.2.14) must be evaluated and compared so that the resultant growing medium will have the desired properties. On a practical basis, however, two factors are the most relevant when selecting growing media: cost and availability of the medium, and seedling performance.

Cost and availability. Regardless of the properties of specific growing medium components, a nursery manager must be able to find and afford the materials before they can be used. Cost is a relative factor, however, and managers should consider all aspects of the situation. Most materials used for growing media are not inherently expensive; the cost of a specific growing medium component is more likely related to transportation costs, which are a function of characteristics such as weight and volume. Bulk ordering of large quantities of growing medium or components can greatly reduce unit cost (fig. 2.2.16). Materials such as sand are readily available and cheap but are so heavy that shipping and handling costs are often prohibitive. Other growing medium components, such as vermiculite, have a large relative volume that also increases transportation costs. Some component materials are unique to one particular area of the country and so nursery managers should first consider local materials before importing growing medium components from some other location. Growers have developed many innovative uses for organic waste materials, which can be substituted for peat moss in growing media (Mastalerz 1977). Container tree nursery

Table 2.2.14—*Quality ratings for some standard growing medium components using cultural and operational characteristics*

	Growing medium components				
	Inorganic			Organic	
Growing medium characteristics	Sand or pumice	Vermiculite	Perlite	Peat moss	Sawdust or bark
Cultural					
Slightly acid pH	V	0	0	+	V
High cation exchange capacity	–	+	–	+	+
Low base fertility	+	+	+	V	+
Large pores for aeration and drainage	+	V	+	V	V
Small pores for water-holding capacity	–	V	–	+	+
Pest-free	V	+	+	V	V
Operational					
Bulk density	+	–	–	–	–
Availability	+	V	V	V	+
Cost	+	V	V	V	+
Uniformity/reproducibility	V	+	+	V	V
Durability/storability	+	+	+	+	V
Changes in volume	+	+	+	V	V
Mixing/filling	+	+	+	V	V
Rewetting ability	+	+	+	–	–
Plug formation	–	+	–	+	V

Rating: + = positive effect, – = negative effect, 0 = no effect, V = variable effect.

Figure 2.2.16—*Most popular growing media components can be ordered in bulk quantities, such as these bales of compressed peat moss; proper storage is essential to avoid contamination.*

managers in some Pacific Islands are investigating native materials for growing media, such as volcanic pumice and the fibrous bark of tree ferns, because any imported material is prohibitively expensive.

The decision to purchase a ready-made commercial growing medium or to mix one's own from individual components (**custom mixing**) is primarily a question of the costs of materials and availability of mixing equipment. Bags of peat moss and vermiculite can usually be purchased more cheaply than a corresponding volume of commercial medium. Sanderson (1983) reported that prepackaged growing media could cost four times as much as custom-mixed media, and Goodwin (1975) estimated that a custom peat–vermiculite medium could be prepared for one-third as much as a commercial growing medium. The real economic consideration is the cost of labor and equipment to do the mixing; because labor and equipment costs vary between nurseries, there can be no standard comparison of costs, and nursery managers must do their own calculations.

Whitcomb (1988) stated that custom mixing batches of growing media can involve significant labor costs. Kusey (1989) listed several different hidden costs that must be considered when comparing commercial and custom-mixed growing media.

Again, because the growing medium is just one in a series of interrelated cultural factors that affect plant growth in a nursery, the prudent grower must consider the overall picture before making a decision about the economics of one particular practice. The combination of cultural practices that produces the best-quality seedling in the shortest period of time and at an acceptable cost will be the most economical in the final evaluation. Kusey (1989) concluded that minor differences in growing medium quality can be reflected ultimately in significant losses in seedling quality.

Seedling performance. Because of the complex relationships between growing media and cultural practices, growers should conduct operational trials of different growing media under their own cultural regimes. Obviously, each nursery cannot afford the time or space to conduct a complicated series of experiments on all the different types of growing media so, initially, managers should rely on recommendations from the literature or from other nurseries.

Small operational trials using different growing media should be attempted on each species of seedling and growing cycle. Nurseries that have implemented such trials have often discovered considerable differences in seedling performance (fig. 2.2.9B).

In the final analysis, the best growing medium for a particular nursery will be a compromise of all the various factors in table 2.2.14, and will be custom fitted to the cultural regime of the specific nursery.

2.2.5.3 Commercial growing media

There are many commercial brands of growing media on the market. Harlass (1984) listed 54 brands of growing media, Judd (1983) reviewed the components of 32 brands, and Sanderson (1983) discussed the components and fertilizer properties of 23 different commercially available products. Some of these products are specially formulated for one specific horticultural crop whereas others are more generic in nature. A few companies offer a growing medium specifically designed for tree seedlings (fig. 2.2.17); whether these

Figure 2.2.17—*There are many different brands of commercial growing media, some of which are formulated for specific crops, including tree seedlings.*

specialized media are better than generic types can only be determined by operational testing at individual nurseries. The Container Nursery Survey revealed that only 35% of the container nurseries in the United States and Canada purchase commercial brands of growing media.

When evaluating different brands of commercial growing media, only sphagnum-based media should be considered for growing forest tree seedlings. Lackey and Alm (1982) evaluated five different types of growing media including two commercially prepared brands contained sphagnum peat moss. The red pine seedlings that were raised in each growing medium were measured for a variety of growth parameters, and also rated for plug formation and seedling quality. The commercial media were consistently better: the Forestry Mix® was superior for all growth factors, whereas the Jiffy Mix® was only significantly better than the custom media in stem height. The plug quality rating and seedling quality indices were uniformly better for the seedlings grown in sphagnum-based commercial growing media (table 2.2.15).

2.2.5.4 Custom-mixed growing media

Based on the Container Nursery Survey, 65% of the forest tree nurseries in the United States and Canada mix their own growing media; five different materials are being used: sphagnum peat moss, sawdust, vermiculite, perlite, and sand. Peat–vermiculite blends were by far the most popular (78%), pure peat media were second

Table 2.2.15—*Performance of red pine seedlings grown in different types of growing media*

Composition of growing media	Stem caliper (mm)	Stem height (cm)	Stem weight (g)	Root weight (g)	Shoot–root ratio	Plug quality rating	Seedling quality index
Custom mixes (using generic peat moss)							
1:1 Peat moss–vermiculite	1.5 ab	8.0 a	0.86 a	0.18 a	4.95 a	2.1	0.10
2:1 Peat moss–vermiculite	1.4 b	7.9 a	0.83 a	0.16 a	5.39 a	1.9	0.09
3:1 Peat moss–vermiculite	1.4 b	7.8 a	0.80 a	0.17 a	4.76 a	2.1	0.09
Commercial mixes (using sphagnum peat moss)							
Forestry* Mix	1.9 c	9.7 b	1.22 b	0.36 b	3.51 b	3.9	0.19
Jiffy* mix	1.6 a	8.9 c	0.92 a	0.19 a	4.85 a	3.9	0.11

Values in columns followed by a common letter are significantly different at P = 0.05.
Source: adapted from Lackey and Alm (1982).

in popularity (11%), followed by peat–vermiculite–perlite (6%) and peat–perlite (2%). The ratio of sphagnum peat moss to vermiculite in the growing media ranged from 1:1 to 3:1, with the 1:1 ratio being the most popular.

For custom-mixed growing media, the author recommends a mixture of coarse-textured sphagnum peat moss and vermiculite. Barnett and Brissette (1986) reviewed the literature and concurred that sphagnum peat moss–vermiculite mixes consistently produce the best quality seedlings. Sphagnum peat moss is the only type of peat moss that is recommended, although other types of peat moss are less expensive. The vermiculite should be grade 2 or 3, the former used for a more porous, well-drained medium and the latter for more water-holding capacity. A small proportion of perlite (10 to 30%) can also be added to increase the aeration porosity of the mix.

2.2.5.5 Comparison of commercial and custom-mixed growing media

Control over quality. Most commercial suppliers have established standards so that the quality of different batches of growing media will remain constant, but nursery managers must rely on the integrity and reputation of the commercial producer. Kusey (1989) advocated the use of commercial media because producers have rigorous quality control programs, and some even have their own testing and research facilities. In custom mixing, however, container tree nursery managers have direct control over the properties of their growing media because the quality of each component can be specifically evaluated.

Ability to "fine-tune" media. Although there is a wide selection of types and brands of commercial growing media available, growers have reported problems in obtaining prepackaged media with specialized properties. Obviously, it is uneconomical for large commercial producers to alter their components and mixing operations to meet small requests. Some local firms have begun to produce custom-mixed growing media, however, and will work with growers to meet their individual needs (fig. 2.2.17). On the other hand, because the nursery manager has control over the proportions and properties of the various components, small batches of custom-mixed growing media can be developed with specific chemical and physical properties, such as pH or aeration porosity, to meet the biological requirements of a particular crop.

Time and labor. Commercial media can be ordered in advance in large quantities, saving time and labor during the container filling operation. Small container tree nurseries, which often cannot afford to invest in mixing equipment or hire the extra personnel to do the mixing, usually find commercial media the most economical and convenient. Although custom-mixing can be done in advance, most nurseries mix their media as part of the container filling process. The extra labor and cost of the

specialized mixing equipment must be considered in the total cost of the media.

Incorporation of fertilizers and other amendments. Many brands of commercial growing media contain limestone to raise the pH of the mix to some optimum value, and others contain a starter charge of nutrients to promote early seedling growth. Surfactants, or wetting agents, are often added to commercial growing media to improve their wettability. The fertilizers, wetting agents, and limestone added to commercial growing media may not be desirable and, in fact, may even be detrimental to tree seedling growth; many brands are formulated for crops other than tree seedlings (see section 2.2.6.3 for more detail).

Uniform mixing. Producers of commercial growing media have the proper equipment and knowledge to produce a well-mixed growing medium. Nursery managers, however, may find it difficult to obtain uniform mixing and even distribution of fertilizers and other incorporated materials with some of the equipment used for custom-mixing. Inexperienced personnel tend to overmix batches of media; overmixing breaks down the physical structure of growing medium particles, leading to compaction problems later in the growing season (see sections 2.2.6.4 and 2.2.7).

2.2.6 Procedures and Considerations for Custom Mixing Growing Media

The mixing process is one of the most important steps in the formulation of custom growing media; the best quality components are of no use if the growing medium is improperly mixed. Whitcomb (1988) emphasized that improper mixing is one of the major causes of variation in container plant quality. The proper operating procedures are just as important as purchasing the right type of mixing equipment. Kusey (1989) stressed that mixing should be performed by diligent, experienced workers who will faithfully monitor the quality of the growing media. Incorporation of fertilizers and supplements must be considered, as well as ways of treating growing media for soilborne pests. Growing media compaction deserves special consideration because it has been shown to be one of the most serious, yet difficult to diagnose, problems in container nursery culture.

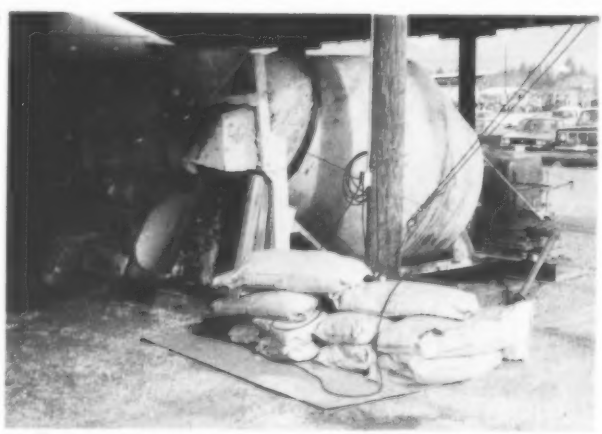
2.2.6.1 Equipment and procedures

Small batch mixing. Smaller nurseries often cannot afford to invest in specialized mixing equipment and prefer to prepare small batches of growing medium by hand. Nelson (1978) states that batches of up to 0.25 m^3 (5 or 6 cubic feet) can be mixed on any clean, hard surface by workers with hand shovels.

To mix components, pile them on top of one another and broadcast any amendments over the pile. Then work around the edge of the pile with a large scoop shovel, taking one shovelful of material at a time and turning it over onto the top of the pile. As this material is added to the top, it tumbles down all sides of the pile and is mixed. Make sure that the center of the pile is mixed by gradually moving the location of the pile to one side during the mixing procedure. Mist the pile with water at frequent intervals during the mixing process to make the medium less hydrophobic. Continue this procedure until samples from the pile appear well mixed.

Mechanized mixing. Nurseries that require larger quantities of custom growing media on a regular basis should purchase a mixer. Several brands of mixers and combination mixers/container fillers are commercially available. Whitcomb (1988) recommended paddle-type mixers in which the drum is stationary and internally mounted paddles blend the components together. Handreck and Black (1984) preferred belt mixers that automatically feed each component onto an adjustable flow conveyor; the mixing occurs when the components fall from the end of the conveyor into a slowly rotating drum or directly into the container mixer/filler. Auger-type mixers, grinders, and soil shredders are not recommended because they break down particle structure and destroy porosity (Judd 1984, Bartok 1985). Modified mixing equipment, such as portable cement mixers (fig. 2.2.18A) with a capacity of 0.1 to 0.2 m^3 (3 to 6 cubic feet) or concrete trucks (fig. 2.2.18B) with a capacity of 4 to 8 m^3 (5 to 11 cubic yards), can be converted into growing medium mixers. Single batch mixers can produce from 0.2 to 9.2 m^3 (0.25 to 12 cubic yards) of growing medium per hour compared to continuous mixing systems, which deliver up to 38.2 m^3 (50 cubic yards) per hour (Bartok 1985).

A



B

Figure 2.2.18—*Various types of equipment have been modified for custom-mixing growing media, including small portable cement mixers* (**A**) *and converted concrete trucks* (**B**).

Any mixing equipment can be specially modified with spray nozzles so that the growing medium can be gradually moistened and with aerated steam injectors for pasteurization (Nelson 1978). Sterility should be maintained during the entire mixing process for both the individual components and the final product (Bartok 1985).

2.2.6.2 Incorporation of fertilizers and other materials

A variety of materials are routinely added to growing media during the mixing process; these include fertilizers, lime, surfactants, and mycorrhizal inoculum. Bartok (1985) stated that 0.76 m^3 (1 cubic yard) of well-mixed growing medium for an ornamental container nursery may contain from 0.45 to 0.91 kg (1 to 2 pounds) of macronutrient fertilizer, 2.27 to 9.08 kg (5 to 20 pounds) of limestone, and 56.7 g (2 ounces) of micronutrients. Uniform incorporation of these materials is important because tree seedling roots only have access to a limited volume of growing media in the relatively small containers used in forest tree nurseries. It is particularly difficult to incorporate small volumes of dry material, such as micronutrient fertilizer, into a moistened growing medium. The probability of obtaining equal distribution of each fertilizer amendment, particularly the small amount of micronutrient fertilizer, to each container is low. Gladon (1988) stated that many early season growing problems are due to improper incorporation of growing medium amendments, and Whitcomb (1988) concluded that uneven mixing of incorporated fertilizers is one of the major factors causing uneven growth in container nursery stock.

Incorporated chemical amendments may separate out during subsequent handling if dry fertilizers are mixed into dry growing medium components (Bartok 1985). Prewetting the growing medium components, such as peat moss and vermiculite, with warm water containing a surfactant will allow the fertilizer and the growing medium particles to aggregate during the mixing process and stop this problem.

Limestone. Limestone, traditionally called lime in horticulture, has been added to growing media in ornamental container nurseries to raise the pH and supply calcium for plant nutrition. Actually, agricultural limestone [calcium carbonate ($CaCO_3$) or dolomite ($CaCO_3 \cdot MgCO_3$)] is used rather than burnt lime (CaO) or slaked lime (CaOH) in horticultural applications (Bunt 1988). Liming is a carryover from the days when soil-based media were common; Williams and others (1988) stated that chemical reactions are different in artificial growing media, however, and therefore liming should be discontinued in modern container nurseries. Liming is still practiced in some forest tree nurseries, such as those in coastal British Columbia, where the irrigation water contains low calcium levels (Gates 1986).

Addition of lime to growing media is not recommended in this manual for several reasons:

- It is operationally difficult to distribute the limestone uniformly during the mixing process (see section 2.2.5.5).

- The naturally acidic pH of most peat-vermiculite media should not have to be greatly increased for most tree seedling crops. Sphagnum peat moss has a pH of 3.5 to 4.0 and vermiculite from 6.0 to 7.6 (table 2.2.1); a mixture of these two components should produce a growing medium reasonably close to the ideal pH range of 5.0 to 6.0. In fact, the initial pH of three typical peat-vermiculite medium had a pH of 4.06 (Scarratt 1986) (Table 2.2.3). It is culturally much easier to raise an initially low pH than lower one that is too alkaline; an acidic growing medium can easily be raised into the ideal pH range through routine irrigation and fertilizer injection. In fact, the pH of container media becomes slightly more alkaline over time due to the effect of bicarbonates in the irrigation water and alkaline fertilizers (Bunt 1988). Gladon (1988) estimated that the pH of a growing medium will rise from one-half to one full unit over the growing season.

- Calcium nutrition can be supplied much more quickly and easily with water-soluble calcium fertilizers (for example, calcium nitrate) than with slowly available limestone or dolomite. Calcium deficiency can be a serious problem with young seedlings because of their restricted root systems, and liquid fertilizer injections would be more effective early in the growing season than incorporated granular fertilizers.

Liming has caused some real problems in operational container tree nurseries. Dangerfield (1978) found that addition of dolomitic limestone to a peat–vermiculite growing medium induced lime chlorosis in Douglas-fir

seedlings, and he concluded that the practice of incorporating lime should be discontinued. Even with broadleaf species, which prefer slightly less acidic conditions, liming is hard to justify. Saligna eucalyptus seedlings were stunted and deficient in several micronutrients, most notably copper, following the addition of dolomite to a peat–vermiculite medium (Miyasaka and others 1983). Chrustic and Wright (1983) concluded that there was no advantage to liming a pine bark–based medium if all the mineral nutrients are provided in the proper concentration and balance. (The nutritional aspects of liming are discussed in more detail in chapter 1, volume four of this manual.)

Fertilizers. Incorporation of fertilizers is a common practice for ornamental stock and sometimes for container tree seedlings, particularly when liquid fertilizer injection equipment is not available or seedlings are grown outdoors in areas with heavy rainfall. Incorporation of micronutrients is more common because artificial growing media are seriously deficient in micronutrients. (A complete discussion of the merits of fertilizer incorporation is provided in chapter 1, volume four of this manual.)

Surfactants. These chemical additives, which are also called wetting agents (fig. 2.2.19), break down the surface tension of water and increase the wettability of hydrophobic organic materials such as peat moss and pine bark. Unfortunately, the chemical and physical effects of these substances on growing media is poorly understood, and some may even be detrimental (Ward and others 1987). Whitcomb (1988) warned that not all wetting agents are safe to use: some are phytotoxic to certain woody plants. Barnett and Brissette (1986) reviewed the literature and reported that in some cases the recommended application rates were too high for tree seedlings. One widely used product (Aqua-gro®) reduced germination of four species of southern pine seed when applied at the recommended 0.1% application rate; reducing the rate to approximately 0.02 to 0.04% provided adequate wetting action without causing phytotoxic effects (Barnett 1977). Pokorny (1979) tested 24 commercial surfactants on pine bark media and found that only 9 were both safe and effective.

Incorporated surfactants may become inactive over time Ward and others (1987) reported that, although initially effective, surfactants may have to be reapplied during the growing season.

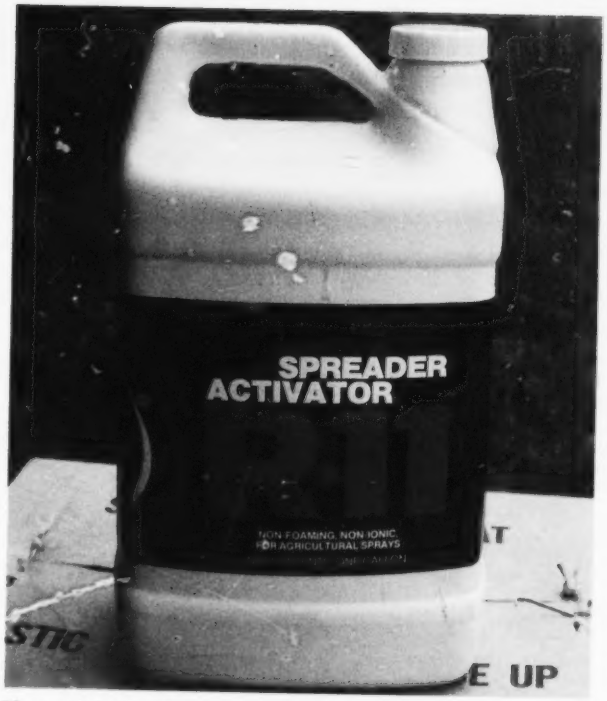


Figure 2.2.19 —*Surfactants (wetting agents) reduce the surface tension of water and are used to increase the wettability of hydrophobic materials such as peat moss.*

Superabsorbents. Superabsorbents are cross-linked polymers than absorb many times their own weight in water. They have been proposed as additives to increase the water-holding capacity of growing media. Several different products are available, however, and not all are suitable for horticultural applications. One class of superabsorbents (propenoate propeamide copolymers) has been shown to increase water-holding capacity, improve aeration and drainage, and reduce the irrigation requirements of growing media (Erazo 1987).

Although they have been added to growing media in ornamental nurseries, superabsorbents are not widely used in forest tree nurseries at the present time. Lennox and Lumis (1987) investigated the use of hydrophilic gels in growing media and found that one additive (Terra-Sorb®) increased the water-holding capacity by only 5%, which is probably not significant for container tree seedling production. In another study, Terra-Sorb was found to increase the water-holding capacity of the growing medium and delayed wilting in tomato seedlings (Adams and Lockaby 1987). Superabsorbents may

not fill a need in most container nurseries at the present time because of regular irrigation scheduling, but their use may be justified in some applications, especially if water use is restricted.

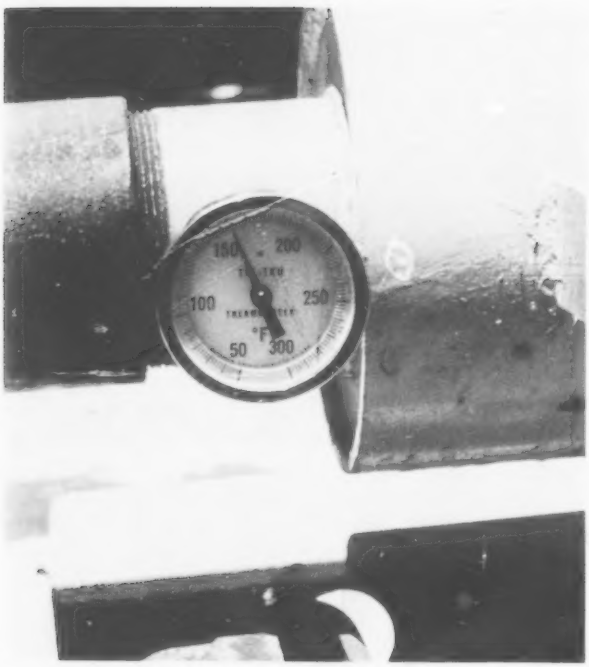
Mycorrhizal inoculum. One method of inoculating container tree seedlings with beneficial mycorrhizal fungi is to incorporate a specially prepared fungus inoculum into the growing medium at the time of mixing. (The benefits of mycorrhizae and the details of the inoculation procedure are discussed in chapter 2, volume five of this manual.) In the future, other beneficial microorganisms, such as plant-growth-promoting rhizobacteria, may be inoculated into growing media (Digat 1988).

2.2.6.3 Pasteurization or sterilization

It has been commonly assumed that artificial growing media are free from soilborne pests, but that assumption has been challenged in recent years. The common inorganic components of growing media, such as vermiculite and perlite, are inherently sterile, but peat moss and other organic components are suspect. A recent outbreak of root disease in conifer seedlings in the Pacific Northwest has been traced to a fungal pathogen in peat-vermiculite growing media (Husted 1988). The exact source of the contamination is not always clear. Peat contamination can sometimes be traced to certain bogs, or areas of bogs, or certain stages during the handling or processing of the peat. The actual extent of growing media contamination is not known, but growers should take certain precautions in the interim.

Some brands of commercial growing media do treat their products and advertise that their mixes are essentially sterile (fig. 2.2.20A). Sterilization refers to the complete elimination of all living organisms in the medium, whereas pasteurization is not as drastic. Completely sterile growing media may not be particularly desirable because many beneficial microorganisms, including bacteria, actinomycetes, and fungi that are normally found in growing media can actually be antagonistic to pathogens (Wolffhechel 1988). Steam heat (fig. 2.2.20B) can be used to either pasteurize or sterilize the media, depending on the temperature. Heat pasteurization is generally thought to be preferable if the proper equipment is available (Bunt 1988); the standard recommendation is to heat the growing medium to 60 to 82 °C (140 to 177 °F) for a minimum of 30 minutes (fig.

Figure 2.2.20—*Some brands of commercial growing media are advertised as being "sterile" (**A**); steam pasteurization (**B**) is beneficial because the relatively low treatment temperature (**C**) can eliminate most soil pests without the loss of beneficial microorganisms.*



2.2.20C). Although chemical fumigation completely sterilizes the media, methyl bromide fumigation has proven effective in controlling some soilborne diseases (Garren and others 1989).

Both pasteurization and fumigation are costly and time-consuming and, like all pest control treatments, have their drawbacks (Bunt 1988). The most prudent procedure may be to have samples of peat moss or premixed growing medium tested for pathogens so that seriously contaminated batches can be identified and treated, or rejected. Purchasing specifications can also be written to require testing for pathogens. These preventative measures, like all pest control treatments, should be part of an overall pest management strategy. (See chapter 1, volume five of this manual for more information on soilborne pathogens and treatment of growing media.)

2.2.6.4 Overmixing and compaction problems

Overmixing can break down the structure of the growing medium particles, which promotes compaction and destroys the aeration porosity of the medium. Fragile materials, such as vermiculite and peat moss, are easily damaged during mixing. Milks and others (1989) found that moistening peat–vermiculite before mixing actually prevented overcompaction, although overly wet components are heavy and will compact easier. In a typical batch of peat–vermiculite medium, the individual peat fibers and vermiculite particles should still be visible (fig. 2.2.21), and the medium should feel spongy in texture; a medium that appears fine or powdery has probably been damaged. Some growers prefer fine-textured growing media because it is easy to load into small containers, but such media tend to pack too tightly in the container and reduce porosity. Overly compacted growing media have reduced drainage and aeration, often resulting in root growth problems (see section 2.2.3.1).

Mechanized mixing can be easily overdone if the mixers are run too long or are overfilled, or if the components are too wet (Whitcomb 1988, Handreck and Black 1984). Certain types of mixers are more damaging than others (see section 2.2.6.1). Most mixers will do an adequate job in 3 or 4 minutes if they are filled only about three-quarters full (Whitcomb 1988). Operational trials conducted on the effect of different mixing times on the size of peat moss particles showed that particle size was severely reduced if mixing times exceeded 5 minutes (table 2.2.16).

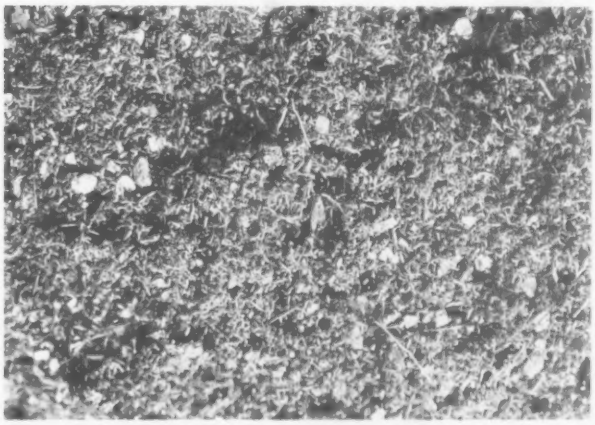


Figure 2.2.21—*A well-mixed growing medium should have a uniform composition with minimal damage to the size or shape of the original components, in this case sphagnum peat moss and vermiculite.*

Table 2.2.16—*The size of peat moss particles can be substantially reduced by overmixing in a mechanical mixer*

Mixing time (min)	Percentage of peat particle sizes				
	Smaller than			Larger than	
	Sieve No. 20 (0.85 mm)	Sieve No. 16 (1.18 mm)	Sieve No. 10 (2.00 mm)	Sieve No. 10 (2.00 mm)	Totals
5	59.4	11.3	11.7	17.6	100.0
10	63.8	11.0	8.0	16.6	100.0
15	70.2	10.5	7.9	11.4	100.0
20	73.5	8.2	7.0	11.3	100.0
25	76.4	8.3	6.6	8.7	100.0

Source: *McDonald (1989).*

2.2.7 The Importance of Proper Growing Medium Compaction

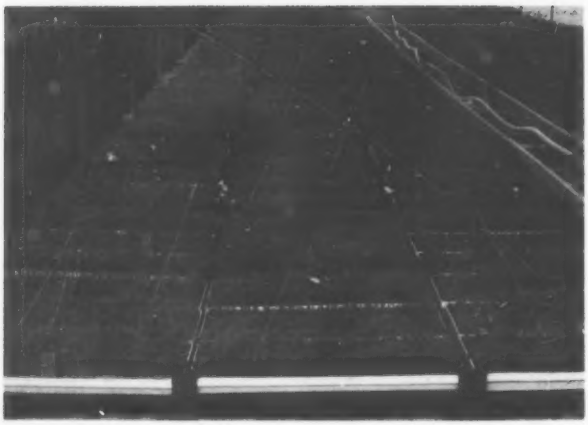
Filling the containers with the growing medium is a critical process. It is important to achieve the proper degree of media compaction, because poorly compacted media can negate the beneficial cultural properties of even the best growing media. Undercompaction is rarely a problem and can be easily diagnosed and corrected. Overcompaction, however, is fairly common due to overmixed media or to excessive mechanical or manual compression during the container filling process (Bunt 1988).

Overcompaction can have several effects on the physical, chemical, and biological properties of a growing medium. Although total porosity is naturally less in compacted media, the more important effect is the reduction or even elimination of the large pores that control aeration and drainage (Bunt 1988). In studies of conifer seedling growth in peat-based growing media that were compressed to various densities, Mitchell and others (1972) found that root activity varied inversely with peat compaction.

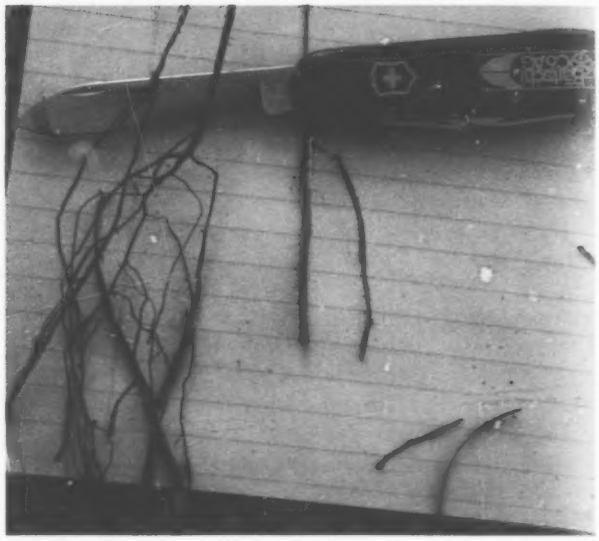
The ideal degree of media compaction will vary with the type of medium, type of container, and irrigation practices at each nursery. Matthews (1983) recommended a growing medium density of 0.1 g/cm^3 of usable container volume for Styrofoam block containers. Hocking and Mitchell (1975) studied the effects of growing medium density in extruded peat containers and found that 0.2 g/cm^3 gave the best seedling growth. Container nursery managers should conduct operational trials to determine the proper growing medium density for their own conditions.

Media compaction is difficult to assess in the small containers used in tree nurseries, and there is presently no reliable technique for measuring it. Several direct observations can be helpful in evaluating growing media compaction, however. Because of the resultant increase in bulk density of compacted media, containers that are unusually heavy should be suspect. During the filling process, the medium should not settle excessively when a container is shaken or tapped on the table. The medium in properly filled containers should still feel springy to the touch. Obviously, evaluation of media compaction in containers is an imprecise process that can be improved only through operational experience. Unfortunately, a container nursery manager only becomes aware of a media compaction problem after seedling growth problems become apparent or during extraction, when poorly formed root plugs are apparent.

The deleterious effects of overcompaction on tree seedling growth are often subtle and difficult to diagnose because of the myriad effects of compaction on the complex rooting environment in a container. Another factor that complicates diagnosis is variation in the degree of compaction that can occur between different blocks of containers, or even between cells within a block, which produces a mosaic of normal and symptomatic seedlings (fig. 2.2.22A). The symptoms of root injury from overcompacted growing media can include foliar chlorosis, leaf drop, root browning, and eventual death. Because it first affects root function, the initial symptoms of overcompaction injury can mimic drought stress, overwatering, or even mineral nutrient deficiency. Mineral nutrient uptake is impaired when roots are not functioning properly due to an overcompacted growing medium; iron chlorosis is just one of the nutritional disorders that can develop (Faber 1982). Roots that become weakened in overcompacted media are particularly susceptible to opportunistic root pathogens such as *Pythium* or *Fusarium* spp. (fig. 2.2.22B). Langerud (1986) reported a root dieback disease of container seedlings that was attributed to poor porosity of the growing medium.



A



B

Figure 2.2.22—*An overly compacted growing media can cause a reduction in aeration porosity, resulting in a variable seedling growth pattern (* **A***); root systems become swollen, lack fine roots and mycorrhizae, and often become infected with fungal pathogens such as* Fusarium *spp. (* **B***).*

2.2.8 Conclusions and Recommendations

The selection of a growing medium is one of the most important decisions in the culture of container tree seedlings. The physical, chemical, and biological characteristics of a growing medium affect not only seedling growth, but also other aspects of nursery operations as well. Container nursery managers, therefore, should carefully consider both biological and operational aspects when evaluating different types of growing media.

Deciding whether to purchase a commercial brand of growing media or to custom-mix will depend on many factors, including availability of components and mixing equipment and the size of the nursery operation. Several good commercial brands of growing media are available but, for complete quality control, container nursery managers should consider custom-mixing their own media.

Whether purchasing a commercial media or custom-mixing, the selection of growing medium components is critical. For container tree seedlings produced in North America, a growing medium consisting of sphagnum peat moss and vermiculite is recommended, if these materials are available and reasonable in price. The proportion of peat moss to vermiculite on a volume/volume basis can range from 1:1 to 3:1. Coarse grade peat moss should be used whenever possible, and the coarser grades of vermiculite are preferred. A small proportion of perlite (10 to 30%) can be substituted for part of the vermiculite if a more well-drained medium is desired. Tree bark, especially composted pine bark, has shown promise as a growing media component in horticultural applications, but more information is needed on this material in forest tree nurseries. Substitution of alternative organic materials for peat moss should be approached cautiously, and only composted organics should be considered.

Chemical amendments to growing media are not usually warranted. Incorporation of limestone or other fertilizer materials into the growing medium is not recommended unless conventional fertilization techniques are unavailable. If possible, pH and mineral nutrient levels should be controlled through injection of acid and liquid fertilizers into the irrigation system. Even though most components are considered sterile, nursery managers should routinely have their growing media tested for pathogenic fungi.

Because the growing medium is just one in a series of interrelated cultural factors that affect plant growth in a nursery, the prudent grower must consider the overall situation before making a decision about the economics of one particular practice. The combination of cultural practices that produces the best-quality seedling in the shortest period of time and at an acceptable cost will be the most economical in the final evaluation. Small-scale operational trials with new types of growing media are always recommended; if trial results appear promising, then the medium can be used on a larger scale.

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